ABSTRACT

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Tornados and other natural disasters are indiscriminate engines of destruction, costing billions of dollars and impacting millions of lives each year. In hopes of minimizing these costs, warning systems are used to distribute warning information and motivate protective action. The Wireless Emergency Alerts (WEA) employed by the National Weather Service (NWS) are of particular interest because they disseminate timely and relevant information to a large number of people on their mobile phones. Human warning response is complex, but models can help illuminate the process. The Communications-Human Information Processing model (C-HIP; Wogalter, DeJoy, & Laughery, 1999) has been studied extensively in the realm of product warnings but not in the context of severe weather warnings on smart phones. The current study investigated the effects of warning information and individual differences on several aspects of warning response within the framework of C-HIP. Four different warnings (default, map only, ratings only, map and ratings) were presented to 74 students during a simulated text message conversation in a repeated measures protocol. Response times were recorded for text messages and warnings. Measures of hazard perception, warning perception, and predicted behavioral response were obtained after each warning trial. Differences in perceptual ratings and response time between warning conditions were observed. The implications of these findings on the study and design of severe weather warnings are discussed from theoretical and practical perspectives.

Using C-HIP to Understand NWS WEA Warning Response

by
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DEDICATION

I dedicate this work to my parents and sister, whose support and encouragement was of immeasurable value.

BIOGRAPHY

Time, for one reason or another, has always held significance in my life. When I first began to self-identify as a runner, time was a medium for competition with others and with myself. Over many miles I learned to appreciate the clock as a benchmarking tool for self-improvement: always comparing my present self to my past self, always trying to become faster. Always trying to spend less time. As an undergraduate, my awareness of time slowly bled into other aspects of my life. Its finitude helped me learn the importance of optimizing one's time to pursue my educational and career goals, participate in extracurricular activities, and foster meaningful and lasting friendships. And of course, I had to make time to run. I stayed busy, but I always felt a sense of uncertainty about the future. Who would I be? What would I be doing? When I left Texas for North Carolina, I hoped those questions would sort themselves out. Twenty-two hours in the car, and the two years that followed left me with more questions than answers. My experiences in the last three years have fostered an appreciation of existing in the present moment. Being "here, now" has helped me accomplish things I used to think were beyond me, and worry less about the things I can't control in the past or future. But there is always room for improvement, and I'm getting better all the time.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

Using C-HIP to Understand NWS WEA Warning Response

Disasters are described as the interaction of a large-scale hazard event, such as a tornado, and the characteristics of the community affected that results in both monetary costs and human suffering (Mayhorn, 2005). Disasters are meaningfully categorized into two types: natural disasters such as extreme weather events and earthquakes, and technological disasters that are the result of a failure in industrial systems. Natural disasters are particularly dangerous because they can be unpredictable and indiscriminate, and thus their potential for damage is colossal. A tornado recently occurred in the south central United States, killing at least 18 people and injuring hundreds. The occurrence of natural disasters such as these has increased sharply in the last two decades. In 2012, 357 natural disasters killed almost ten thousand people and affected an additional 125 million (Guha-Sapir, Hoyois, & Below, 2012). These human costs were also accompanied by economic damages of over $150 billion, a higher amount than the average economic damages of the last decade (Guha-Sapir et al., 2012). The potential impacts of disasters are expected to increase due to population growth and urbanization (Lowrey, Evans, Gower, Robinson, Ginter, McCormick, & Abdolrasulnia, 2007). In fact, a recent Intergovernmental Panel on Climate Change (IPCC) report indicated that recent extreme weather events have revealed significant infrastructure vulnerabilities that, when exploited, could result in property damage, higher mortality rates, and lower human well-being (IPCC Working Group II, 2013). Further, natural disasters present a unique problem for human factors practitioners because they are the result of forces of nature beyond human control. Therefore, the best way reduce their impact is to employ timely and effective warnings (Hitt II, Mouloua II, & Morris II, 2000).

Disaster warning systems are comprised of three high-level components: hazard detection, emergency management, and public communication (Sorenson & Mileti, 1987). The hazard detection component is very complex. For example, a tornado detection system requires the use of numerous sensors, forecasting models, and predictive formulas operating in synchrony to be timely and effective (Brotzge & Donner, 2013). Once a hazard is detected, or considered likely to occur, a warning is issued.

Perhaps the most well-known implementation of the public communication aspect of disaster warning systems is the National Weather Service's (NWS) Wireless Emergency Alerts (WEA). Formerly known as the Commercial Mobile Alert System (CMAS), the WEAs provide government officials with a means to communicate warning information to specific geographic areas (Federal Communications Commission [FCC], n.d.). First, NWS officials provide warning information to wireless carriers participating in the WEA program. Then, the carriers distribute the warning information to mobile phones using cellular towers within the affected area (FCC, n.d.). Importantly, these messages are different from normal personal communications because they utilize unique visual and tactile displays (FCC, n.d.).

Recent efforts have been made to enhance disaster warning systems as a means to improve disaster preparedness in response to more frequent and costly disasters (Golnaraghi, 2012). Hopefully, warning systems and capabilities will continue to improve, further reducing the impacts of future natural disasters (Hitt II et al., 2000; Mayhorn, Yim, and Orrock, 2006). One way to develop meaningful improvements to disaster warnings is to understand how humans respond when they receive such a warning.

Human Behavior in Disaster Situations

By the time a warning is distributed through public communications, it reaches a population that may or may not be aware of the imminent danger. One's first response is typically that of denial, due to the normalcy bias (Drabek, 1999). Then, in an attempt to cope with the changing circumstances, warning recipients begin to seek more information, often by checking the radio, television, or by conversing with others (Mikami & Ikeda, 1985). In conversing with others, these individuals will also reach out to family and others to confirm their safety and share information (Mikami & Ikeda, 1985). The social context of disaster warning response is particularly important, because people rarely encounter such events in complete isolation (Drabek, 1999). Naturalistic disaster response research has confirmed these social tendencies; in-person interaction, phone calls, and other forms of communication were commonly mentioned channels of information during and after a series of tornados and their aftermath (Shreeves & O'Brien, 2013).

The Protective Action Decision Model (PADM; Lindell & Perry, 2012), based on the classical persuasion model, describes the flow of information that individuals use to make decisions about protective action (see Figure 1). In a disaster situation, one acquires information from the environment, from social cues, and potentially from warnings. Using this information, and factoring in one's own beliefs, one may determine that the situation is not normal and therefore will initiate the decision-making process. The process begins with a few considerations: one's perception of the threat, the options for protective action, and other individuals that may also be threatened, such as family and friends. Once the relevant factors are considered, the individual then decides the best course of action, and a behavioral response results. The optimal response is for one to elicit problem-focused coping in the form of protective action (Lindell & Perry, 2012). However, individuals may also engage in emotion-focused coping, or may seek more information if they do not have enough information to make a decision. Therefore, sufficient and accurate information is a critical component of the protective action decision-making process; lack thereof will result in seeking more information, a behavior that ultimately delays protective action in time-limited scenarios.

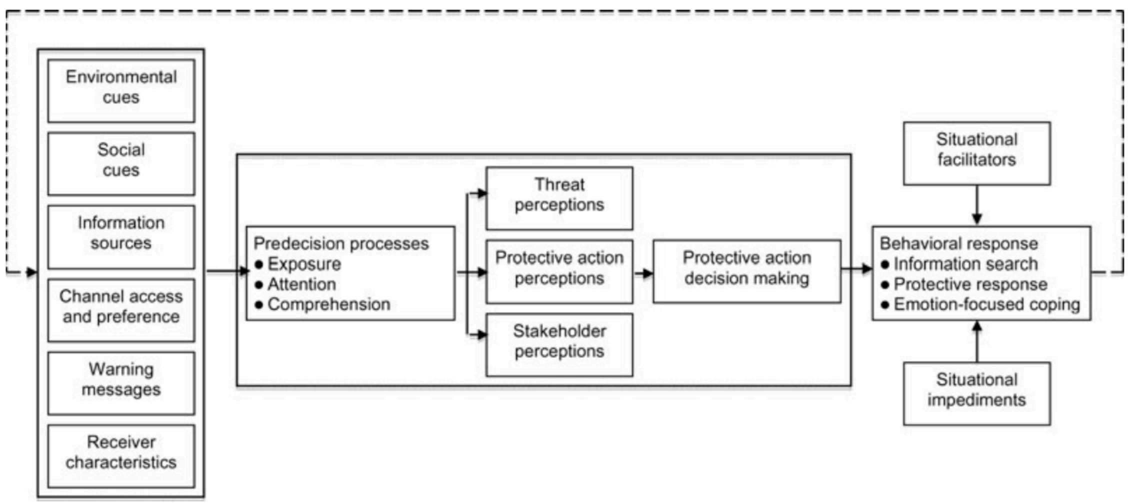

Figure 1. Illustration of the information processing stages of the Protective Action Decision Model (PADM). Adapted from "The Protective Action Decision Model: Theoretical Modifications and Additional Evidence," by M. K. Lindell and R. W. Perry, 2012, *Risk Analysis*, 32, p. 617.

In the first stage of the PADM, warnings play a key role in providing information and potentially altering one's perception of the situation. Clarity and credibility are paramount, as reliable information may expedite the protective action behavioral response. A similar model, the Communication-Human Information Processing model (C-HIP; Wogalter, DeJoy, & Laughery, 1999), details the flow of warning information, and how that information might influence one's perceptions, and therefore influence behavior (see Figure 2). The model is comprised of three stages: the source, channel, and receiver (Wogalter, 2006). The source is the entity that develops the warning message. In the case of natural disasters, this is usually a public service organization like the National Weather Service. Certain characteristics of the source, such as credibility and familiarity, qualify the warning message and may promote or inhibit a change in beliefs (Conzola & Wogalter, 2001). The source employs a particular channel, or channels, to disseminate the warning message. The characteristics of the channel may also impact one's attention to and perception of the warning. For natural disasters, warnings are often presented in a variety of media, including audible warnings over the radio, and visual warnings on the television, phone, or computer.

Once the warning message reaches the receiver, it is filtered through several information processing stages before it finally elicits a behavioral response (Conzola & Wogalter, 2001; Laughery & Wogalter, 2006; Wogalter, 2006). In the first of these stages, the warning must attract the receiver's attention; a warning that does not capture attention will therefore have no impact on the receiver. Further, a warning must garner sustained attention long enough to allow for perceptual processing. When the warning is noticed, the receiver must then comprehend the warning message. Failure to comprehend a warning message may elicit an incorrect appraisal of the situation, and could result in inappropriate or potentially dangerous behavior. The next processing stage is a comparison of the warning content to one's existing beliefs and attitudes. If the message is not consistent with one's beliefs, an effective message would result in a change in said beliefs. If the message is consistent, those beliefs are reinforced and an appropriate behavior is more likely to occur. The final receiver stage is one of motivation. One will be sufficiently motivated to comply with the warning if the perceived costs of compliance are lesser than the costs of noncompliance. Each processing stage has feedback loops to all of the previous stages, meaning that the receiver could process the warning through these stages numerous times before making a decision about their behavioral response. Factors that impact each of the receiver stages will be discussed in detail in a later section of this paper. If the warning message successfully passes through each of the aforementioned information processing stages, one's behavioral response will be that of compliance with the warning message (Laughery & Wogalter, 2006; Wogalter, 2006).

The PADM was developed to describe the human decision-making process in hazardous situations, whereas the C-HIP was developed to describe the cognitive processing that occurs in the warning process (usually in the context of consumer products). The models are similar in that they both illustrate the crucial role of warning information and communication in hazardous situations. To date, the C-HIP has not been directly applied to disaster warnings, but it provides a framework to understand the effects of disaster warnings from the perspective of human cognition. By supplementing our understanding of human behavior in disasters with an investigation of disaster warnings through the information processing stages of the C-HIP, it is possible to develop meaningful warning design changes that may increase compliance with the recommended protective action.

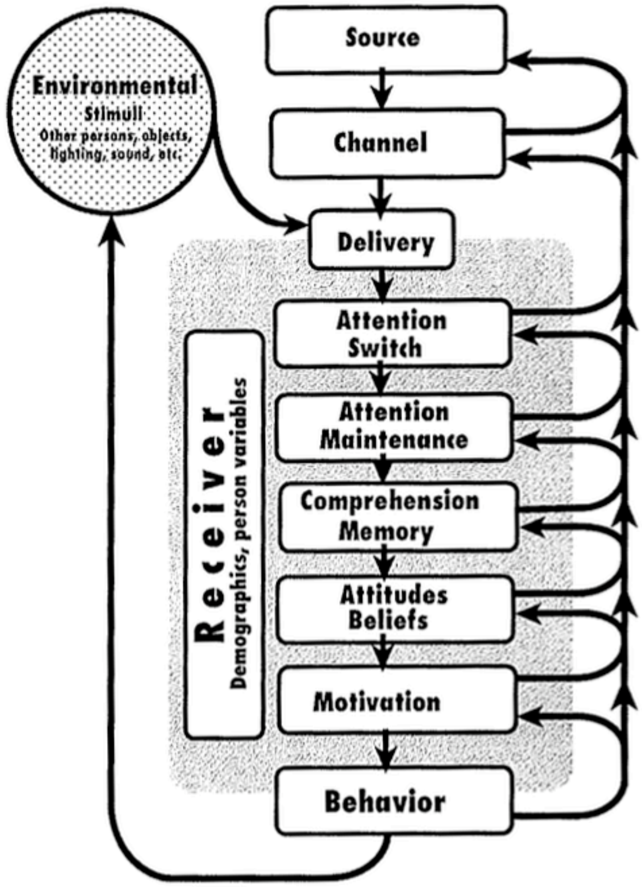

Figure 2. Illustration of the information processing stages of the Communications-Human Information Processing (C-HIP) model. Adapted from "Communications-Human Information Processing (C-HIP) model," by M. S. Wogalter, 2006, Handbook of Warnings, p. 52.

Warnings

In general, the primary purposes of warnings are to communicate information in support of decision-making, to cue knowledge of safety behaviors, to persuade the performance of safe behavior, and to prevent harm to both people and property (Conzola & Wogalter, 2001; Wogalter & Feng, 2010; Wogalter & Mayhorn, 2005). The product warning literature agrees that humans process warnings in four stages: noticing, encoding, comprehension, and compliance (Wogalter, Conzola, Smith-Jackson, 2002). Noticing and encoding are often considered in tandem, and pertain to the attentional and perceptual aspects of the warning. Comprehension refers to the extraction of information from the warning. Compliance refers to one's behavioral response to the warning. Importantly, characteristics of the warning itself as well as characteristics of the person being warned influence the effectiveness of the warning at every stage of the warning process (Rogers, Lamson, & Rousseau, 2000). The disaster warning literature refers to these two factors as warning characteristics and receiver characteristics, and adds a third unique factor of hazard attributes (Mayhorn & McLaughlin, 2014). Each of these factors will be detailed in the following sections.

Hazard Attributes

As mentioned previously, disasters can be categorized into one of two broad types: natural and technological. Technological disasters are those associated with industrial systems; the Deepwater Horizon explosion (Geiger, 2011) and the Fukushima Dai-ichi reactor crisis (Patel, 2011) are recent examples of such disasters. These events are catastrophic in nature, but quite infrequent. Natural disasters, on the other hand, occur with much greater frequency. For example, the National Oceanic and Atmospheric Administration's (NOAA) National Climatic Data Center indicates that over 1200 tornados occur in the United States each year (Crouch, Heim, Jr., & Fenimore, 2013).

Despite their frequency, few lives are lost to tornados. Existing research credits the extremely low fatality rate to the efforts of the National Weather Service's warning systems

(Simmons & Sutter, 2008). Interestingly, compliance with natural disaster warnings is lower than technological disaster warnings because of their frequency and familiarity (Mayhorn & McLaughlin, 2014). Familiarity with natural disasters tends to elicit complacency, often resulting in less awareness and failure to prepare and respond when a natural disaster actually occurs (Balluz, Schieve, Holmes, Kiezak, & Malilay, 2000). This is problematic because natural disasters can be just as costly and destructive, and we have better means of predicting and warning about them than we do about technological disasters. Therefore, further improvement of natural disaster warnings is warranted. The current research focused on tornados and tornado warnings because they are relatively common in the region where the research was conducted.

Receiver Characteristics

Receiver, or person, characteristics refer to the personal factors that influence one's processing of warnings. It is important to study and understand such characteristics because each individual is influenced by their own unique combination of them, resulting in a potentially vast array of individual differences in warning perception and response (Helton, Kemp, and Walton, 2013). The receiver characteristics outlined by the C-HIP model will be detailed in the following sections.

Attention Switch and Maintenance. Existing research indicates that the incidence of a disaster scenario elicits an experience of heightened arousal and cognitive disruption (Helton & Head, 2012; Mikami & Ikeda, 1985). Helton and Head (2012) found that post-earthquake performance on a sustained attention task elicited more errors of omission than performance measured prior to an earthquake, suggesting that participants were experiencing cognitive disruptions that interfered with their ability to perform the task without errors. Interestingly, one's performance degradation was influenced by individual differences in post-disaster stress response such that attention was worsened with a more severe stress response (Helton & Head, 2012). Therefore, disaster warnings must be designed to overcome sub-optimal attentional abilities in disaster scenarios. The relative shortage of findings in this area warrants further exploration of attention as a potential predictor of warning comprehension and compliance.

Comprehension. Warning comprehension depends on both the cognitive abilities of the receiver as well as the brevity and clarity of the warning message (Conzola & Wogalter, 2001). Message characteristics will be explored in a later section. Cognitive ability can be ascertained through measurements of education level, or measured more directly through a variety of cognitive measures. For instance, a telephone survey was conducted in two counties that experienced particularly severe consequences from a recent tornado (Balluz et al., 2000). The study found that individuals with at least a high school education were more likely to comply with a tornado warning than those with less education (Balluz et al., 2000). Little research exists on the cognitive abilities that influence disaster warning comprehension. The current research effort measured participants' working memory, a construct that has been used as a predictor of cognitive ability in a variety of fields and applications (Unsworth, Heitz, Schrock, & Engle, 2005).

Beliefs and Attitudes. A great deal of research exists pertaining to the effects of preexisting beliefs and attitudes on disaster warning response. It is through these beliefs and attitudes that the most drastic impacts of individual differences occur, because they are informed by each individual's unique experiences (Drabek, 1999). At times, these differences are observed in specific demographic segments. For example, younger individuals tend to respond more quickly than older individuals, attributed to their relative inexperience and greater perceptions of vulnerability, whereas older individuals perceive less risk due to their numerous life experiences (Drabek, 1999). Even a gender effect has been observed such that women are more likely to take protective action, but this is likely due to differences between genders in one's perception of risk and vulnerability (Drabek, 1999; Helton et al., 2013). Another effect, observed primarily in minority and lower income populations, is that lack of trust in authority figures leads to slower warning responses, due to the need to verify the information with other sources (Drabek, 1999). Conversely, information from preferred or consistently reliable sources has been shown to be one of the most frequently used pieces of information when making protective action decisions (Shreeves & O'Brien, 2013). Therefore, one's attitudes about the source of warning information are of paramount importance to the individual's perception of and compliance with the warning message. It is important to understand that these effects are not caused by one's inherent demographic, but rather by unique experiences or beliefs that occur within those demographic segments. In sum, perceptions of risk, danger, vulnerability, source credibility, and the like have been well-studied in the disaster warning literature, but are no less important factors in one's warning response.

The importance of prior experience with disasters on warning response has been supported by numerous studies. More recently, research has been conducted to clarify and understand those prior experiences in greater detail. Sharma and Patt (2012) conducted a household survey in two areas that had recently experienced a cyclone. The study found that individuals who had experienced a cyclone after being warned, had evacuated in a previous cyclone event, or were aware of deaths in the community during previous cyclone events were more likely to comply with an evacuation recommendation. Furthermore, the belief that one's basic needs would be met in a storm shelter was associated with evacuation behavior (Sharma & Patt, 2012). Conversely, prior experience with false alarms was a predictor of deciding not to evacuate (Sharma & Patt, 2012). In the product warning literature, research conducted with computer-related warnings demonstrated a similar finding that expectations of low alarm reliability lead to fewer alarm responses, and behavioral indicator of alarm mistrust or the "cry-wolf" effect (Bliss, Gilson, & Deaton, 1994). Considering that tornadoes have a higher false alarm rate than other severe weather events (Barnes, Gruntfest, Hayden, Schultz, & Benight, 2007), it is highly likely that many will not take the necessary protective action when faced with a tornado warning. These findings provide strong evidence for the measurement of hazard perceptions and prior disaster experiences as predictors of warning response. The current research measured several aspects of hazard perception and prior hazard experience as predictors of warning response.

Motivation. In the warning process, motivation is defined as the contrast between costs of compliance and the costs of noncompliance. If the costs of compliance are high, they effectively act as disincentives for taking protective action. For example, a survey study found that individuals who lacked a basement or did not have access to a community storm shelter did not comply with the warning recommendation to take shelter (Balluz et al., 2000). In this case, difficult or lack of access to shelter was a high cost of compliance. However, being prepared for disaster (Sherman-Morris, 2013) or having a plan of action for hazardous circumstances (Balluz et al., 2000) can reduce these costs and thus encourage compliance. Conversely, the costs of noncompliance are often factors such as threats of injury or death if one fails to take protective action, though these costs are often discounted by the normalcy bias (Drabek, 1999; O'Brien & Shreeves, 2013). Therefore, sufficient motivation is reached only when the costs of noncompliance outweigh the costs of compliance.

Hazard attributes and receiver characteristics are both important inputs in influencing an individual's response to a warning message. However, warning designers cannot control the attributes of a hazard, and they must accommodate a variety of individual differences to implement an effective disaster warning. Therefore, a great deal of emphasis should be placed on the characteristics of the warning itself, and on understanding how to elicit the optimal warning response across a wide variety of individuals and situations.

Warning Characteristics

Disaster warnings are a unique application of the warning process because they are deployed strategically to protect those who might be affected by a natural or technological hazard. As such, they are quite different from product warnings because they are often the only means of protective information available for the individual being warned, at least initially. Thus, a thorough understanding of all the elements of a disaster warning is warranted. Using the C-HIP model as a framework, we can organize warning attributes by source, channel, and content of the warning.

Source. When an individual receives a warning from the source, the individual must make a judgment about the credibility of that source. If the warning comes from a source that the individual trusts, they are more likely to comply with the warning (Drabek & Stephenson, 1971). In the presence of a technological disaster, warnings are usually sourced from the private sector, and are often perceived in a negative light due to the admission of responsibility from the private firm (Coombs, 1995). However, for natural disasters, warnings usually come from the public sector as a service to promote public safety, and are typically viewed more amicably compared to those from private firms (Freberg, Saling, Vidoloff, & Eosco, 2013). Governmental and meteorological organizations are common, but not the only, sources of warning information. A cognitive task analysis study revealed that peers, local media, and social or environmental cues were among the most frequently mentioned sources of information about an approaching severe weather event (Shreeves & O'Brien, 2013). Interestingly, individuals recognized as personal authorities, like parents or employers, were mentioned as much as the NWS as the source of information for the weather events (Shreeves & O'Brien, 2013).

Channel. As mentioned previously, the channel used to communicate a disaster warning is a critical component of the warning's effectiveness, as the channel has certain characteristics such as temporal proximity, message specificity and length, and precision in reaching the target audience (Mayhorn & McLaughlin, 2014). The product warning literature suggests that temporal and spatial proximity are beneficial for increasing warning compliance (Wogalter & Conzola, 2002; Wogalter & Mayhorn, 2005). Mobile phones are of particular interest as a warning channel. Mobile phones are nearly ubiquitous, and many of those phones are internet-capable smart phones. In fact, smart phones now outsell basic mobile phones globally (Gartner, 2013).

Warnings received through one's phone are potentially helpful for a number of reasons. Marketing research reported that the average mobile phone user looked at his or her phone more than 150 times per day (Meeker & Wu, 2013). A separate study from an application developer indicated the number was 110 times per day (Hu, 2013). Assuming one is awake for 18 hours each day, these findings imply that a glance at one's phone occurs every seven to nine minutes, on average. These data suggest that mobile phone users pay a great deal of attention to their phones, therefore it is logical to suggest that warnings presented through the mobile phone channel are highly likely to elicit attention. Furthermore, the wireless capabilities of mobile phones help to circumvent the infrastructure requirements, and thus limitations, of warnings distributed via television or radio. These limitations were evident during the Super Tuesday tornado of 2008, a storm that disabled some of the electrical infrastructure and thus prevented warning information from being broadcasted on television (Chaney & Weaver, 2008). Mobile phone warnings, on the other hand, are implemented such that they do not interfere with any other communications and are disseminated with the highest priority and immediacy, ensuring that they are received (FCC, n.d.).

In addition to making calls and sending text messages, smart phones can also access the Internet, greatly increasing one's communication options. Smart phones can receive information from many sources, through a variety of channels, and facilitate the sharing of that information with others (Casteel & Downing, 2013). An example of this capability is the use of social media as a warning channel in a disaster scenario. A recent earthquake illustrated that information about the earthquake could actually be communicated through

Twitter faster than the effects of the earthquake could spread (Crooks, Croitoru, Stefanidis, & Radzikowski, 2013). Social media, particularly when accessed from a smart phone, are a rich channel of communication that can be directed at specific individuals or groups. Communications within these networks can contain pictures, videos, or links to other content from the web. Social media communications can also contain geographic information that is particularly helpful for disaster warnings (Crooks et al., 2013). The relevance and richness of information disseminated through social media may be part of why it is such an effective channel for disaster warning information. It is possible that emulating these properties may increase the effectiveness of the NWS WEA warnings on smart phones.

Finally, mobile phone communications can employ multimodal notifications by using a combination of tactile, audible, and visual stimulation in various combinations. The use of non-visual warning cues is particularly helpful in situations when one's visual resources are already considerably taxed (Haas & van Erp, 2014). Existing research supports the notion that tactile displays such as the non-directional vibration used in phones are helpful for attracting attention, and can also pair with a visual display to communicate more detailed information (Haas & van Erp, 2014). Importantly, NWS WEA messages employ a unique vibration pattern so as to differentiate the warning messages from other communications (FCC, n.d.). The literature suggests that this differentiation can overcome one's habituation to other tactile displays, such as those utilized by other communications, therefore increasing the likelihood of noticing the warning (Wogalter & Mayhorn, 2005). Interestingly, research on the duration of tactile pulse duration did not find differences in perceived urgency at intervals above 200 ms (Lewis, Eisert, & Baldwin, 2014). However, this research employed tactile displays at the wrist, belt area, and seat pan for application in a driving environment (Lewis et al., 2014), and therefore the findings may not apply to mobile phone tactile warnings that accompany a visual display. To simulate notifications naturalistically, the current research implemented the unique tactile notification patterns for text messages and NWS WEA alerts to aid participants in differentiating between the two types of notifications.

Content. Closely linked to the warning channel, the content of the warning message is highly dependent on the capabilities and limitations of the channel it is communicated through. According to the American National Standards Institute (ANSI), warnings must contain four pieces of information: a signal word, a description of the hazard, the consequences of noncompliance, and instructions for hazard avoidance (American National Standards Institute [ANSI], 1998). Similarly, disaster warning messages should communicate source information, information about the hazard, the area that may be affected by the hazard, the time period when the hazard might occur, probability of the hazard occurring, environments of especially high risk, and suggested protective actions (Drabek, 1999). The aforementioned NWS WEAs adhere to most of these requirements, providing hazard information, the predicted time course of the hazard, the predicted area to be affected, and protective action recommendations (Mayhorn & McLaughlin, 2014; see Figure 3).

Although the NWS WEA warning messages have not been specifically studied, existing research has indicated that other information is also beneficial for influencing disaster response behavior in other scenarios. One such study provided short descriptions of a disaster scenario and asked participants to indicate what action they would take in response to the scenario (Hitt II et al., 2000). The researchers found that providing information about the strength of the storm, the frequency of false alarms, and the current weather conditions were all significant factors in self-predicted protective action (Hitt II et al., 2000). Similarly, Sharma and Patt (2012) suggested that providing additional information about the uncertainty of the warned hazard may help overcome hesitation in warning response after experiencing false alarms.

WEA Messages Originated by NWS

	Warning Type	WEA Message
Extreme	**Tsunami Warning** (coming late 2013)	Tsunami danger on the coast. Go to high ground or move inland. Check local media. –NWS
Extreme	**Tornado Warning**	Tornado Warning in this area til hh:mm tzT. Take shelter now. Check local media. –NWS
Extreme	**Extreme Wind Warning**	Extreme Wind Warning this area til hh:mm tzT ddd. Take shelter. –NWS
Extreme	**Hurricane Warning**	Hurricane Warning this area til hh:mm tzT ddd. Check local media and authorities. -NWS
Extreme	**Typhoon Warning**	Typhoon Warning this area til hh:mm tzT ddd. Check local media and authorities. -NWS
Severe	**Flash Flood Warning**	Flash Flood Warning this area til hh:mm tzT. Avoid flooded areas. Check local media. -NWS
Severe	**Dust Storm Warning**	Dust Storm Warning in this area til hh:mm tzT ddd. Avoid travel. Check local media. -NWS

Legend
tzT = timezone
ddd= three letter abbreviation for day of the week

Figure 3. Wireless Emergency Alerts originated by the National Weather Service. This figure illustrates the general structure and content of weather event alerts.

The NWS WEA messages are somewhat abbreviated compared to the information provided in the NWS Common Alerting Protocol (CAP) messages (Organization for the Advancement of Structured Information Standards [OASIS] Emergency Management Technical Committee [TC], 2005). The CAP messages include additional information such as certainty, urgency, and severity ratings for each weather event, as well as a detailed description and instructions for an appropriate response (OASIS Emergency Management TC, 2005). This supplementary information exists for each severe weather warning, therefore it is reasonable to draw from this resource to bolster the information provided in NWS WEA warnings. Specifically, the current research explored the impact of providing hazard certainty, urgency, and severity on warning perception and response.

The use of graphics as additional or supporting information is common in both product warnings (Wogalter et al., 2002; Wogalter & Conzola, 2002; Wogalter & Mayhorn, 2005) and disaster warnings, though the latter are less well studied. Casteel and Downing (2013) investigated the effects of providing an overhead map view in addition to the full NWS tornado and flash flood warning text. Interestingly, response times, accuracy, and warning perceptions did not differ in the presence or absence of the overhead map, suggesting that perhaps the map image used in the study was not effective for improving warning comprehension or altering warning perceptions (Casteel & Downing, 2013). However, it is possible that alternative designs could be more effective. In fact, one such study sought to improve the notoriously confusing cyclone warning map image, and ultimately provided recommendations based on qualitative and preferential data from a large sample (Radford, Senkbeil, & Rockman, 2013). Overhead map images have a great deal of merit in disaster warning applications. Existing research suggests that one's location data, ascertained using the GPS receiver in smart phones, could provide an effective level of warning specificity and personalization (Wogalter & Conzola, 2002). However, this data was not represented in Casteel and Downing's (2013) research. Therefore, the current research investigated the effects of different overhead map designs that incorporated GPS location data on warning perception and response.

Current Study

The objective of the current research was to investigate how additional information might impact one's perception of and response to NWS WEA severe weather warnings. The methodology for this research was adapted from the product warning literature (Mendel, Mayhorn, Hardee, West, & Pak, 2010), the disaster warning literature (Casteel & Downing, 2013; Helton & Head, 2012; Hitt II et al., 2000), and the driving performance literature (Heenan, Herdman, Brown, & Robert, 2014). Of primary importance, and the basis for the first hypothesis, was the impact of warning information on hazard and warning perception. Participants' ratings of hazard perception, warning perception, and self-predicted behavioral response after each of several warning presentations were collected. It was hypothesized that the provision of additional information within the warning messages would result in differences in perceptual ratings on the hazard perception scale items (Hypothesis 1A), warning perception scale items (Hypothesis 1B), and self- and other-predicted behavioral response items (Hypothesis 1C).

Rather than requiring participants to simply respond to warnings presented on a phone, a text-messaging task was designed to simulate a logical use case when one might receive an unexpected NWS WEA warning. Furthermore, this method enabled the recording of warning response time as well as text message response time before, during, and after the warning is received. To examine differences in cognition required to process and respond to each warning, warning response times were compared between conditions, and it was hypothesized that warnings presenting more information would thus elicit longer response times (Hypothesis 2). Similarly, a comparison of the average text message response times before and after warning presentation was used to investigate the occurrence of momentary cognitive disruption linked to warning presentation; it was hypothesized that response times will be greater after warning presentation (Hypothesis 3).

A number of individual differences play a role in one's processing of and response to warning messages. The current research sought to quantify some of those differences using measures of cognitive ability and preexisting beliefs and attitudes about hazardous weather. The fourth and fifth hypotheses investigated the impacts of individual differences in cognitive ability. It was hypothesized that there would be differences in warning response time (Hypothesis 4) and text message response time (Hypothesis 5) based on one's attentional and working memory abilities. The sixth and final hypothesis explored the relationship between one's beliefs and attitudes about hazardous weather on hazard perception, warning perception, and self-reported behavioral response. It was predicted that differences in beliefs and attitudes would result in differences in hazard perception, warning perception, and predicted behavioral response (Hypothesis 6).

Method

Design

The experiment implemented a 4 x 3 within subjects factorial design. Participants were exposed to all four warning conditions (default, map only, ratings only, map and ratings) in a random order. In addition, within each condition, participants experienced three warning phases (before warning, warning, and after warning). Condition and warning phase were compared within-subjects. Measurements of cognitive ability, perceptions of weather hazards, and prior experience with weather hazards were also obtained and compared between-subjects.

Participants

A convenience sample of undergraduate and graduate students were recruited through the Experimetrix website and through extra credit opportunities in two psychology courses. Students received course credit for their participation in this experiment. To qualify for participation in the study, participants were required to demonstrate adequate color vision, 20/20 visual acuity, and have prior experience using smart phones. Of the 82 participants recruited for participation in this study, four participants failed to demonstrate adequate color vision and three failed to demonstrate 20/20 visual acuity and were thus excluded from further participation. Additionally, one participant was excluded after the fact because his/her data indicated that this participant repeated a condition, and thus did not follow instructions. Using G*Power 3.1 to conduct an a priori power analysis (Faul, Erdfelder, Lang, & Buchner, 2007), with the parameters of a repeated measures, within factors MANOVA, an alpha level of .05, a power level of .8, three groups, and four measurements, a sample size of 73 was required to identify an effect of (.2). After exclusions and given available time and resources, the current research sampled 74 students.

Apparatus and Materials

Devices. Participants used two devices while completing the study: a laptop and a smart phone. The laptop was a Dell Precision M4500 laptop running Windows 7, connected to an Acer g195w display, Dell keyboard, and Dell corded mouse to create a more comfortable workstation for participants to use. The phone was a LG Nexus 4 smartphone running Android OS 5.1.1 Marshmallow. Participants always used the phone in portrait orientation, and used the software keyboard to compose text message responses.

Web application. A website was developed to display the text messages and warning stimuli. The first page of the website, the launcher page, displayed five pink rectangular buttons (Figure 4). The first button was labeled “Practice Trial” and the remaining buttons referred to each of the four conditions, lettered A through D. Selecting one of the buttons would begin the task flow of the corresponding condition. Each task flow consisted of a buffer page to record participants’ unique ID numbers and to provide instructions, the text-messaging conversation, and another buffer page that indicated completion of the condition and provided a link to return to the launcher page. Lettered conditions also included a warning stimulus. Implementation of the text-messaging task and warning stimuli are detailed below.

The text message conversation was framed as a modified form of the Twenty Questions Task (TQT; Horrey, Lesch, & Garabet, 2009). Traditionally, the TQT employs two roles: those of the questioner and the answerer. The object of the task is for the questioner to guess a specified word by asking the answerer a series of yes or no questions. The answerer is to respond truthfully to those questions with “yes” or “no”. Existing research has implemented the TQT as a means of fostering the use of information integration and working memory in an engaging manner (Horrey et al., 2009). The conversational nature of the TQT is also more naturalistic than most laboratory-based tasks, and existing research has validated it as an adequate proxy for natural conversation (Heenan et al., 2014). For the purposes of the current study, the questioner was simulated in the web application as the sender of all text messages, so as to automate the task and eliminate the need for additional research personnel. The participant used the text-messaging interface to respond to the questions.

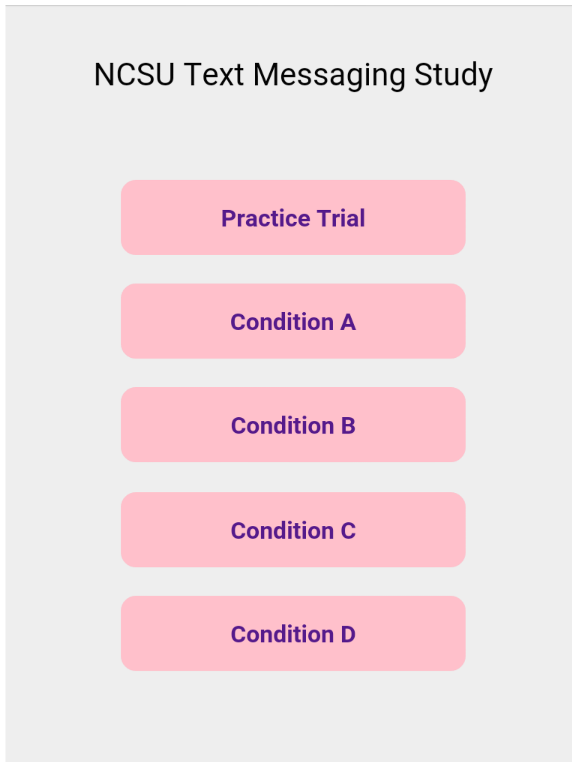

Figure 4. Launcher page of warning stimuli website. This figure illustrates the buttons that were used to administer specific warning conditions to participants using the website.

The text message pages were designed to resemble a generic text-messaging application on a smartphone (see Figure 5). Upon each page load, the phone produced a tactile vibration for two short intervals (300 ms each) separated by a brief pause (200 ms) to simulate a text message vibration notification. The page itself displayed the following elements: a header bar, a received text message, and an input form. The header bar indicated the name of the recipient of the simulated text messages, as well as back arrow and ellipsis buttons. These elements are conventions seen in most text messaging applications, but were not functional because they were not necessary for this research. The text message, a blue rectangle below the header bar, displayed a random question drawn from a database of questions used in the 20 Questions task (see Appendix A). The input form was located at the bottom of the page and displayed the placeholder “Send message” to indicate its functionality. To the right of the form was a “Send” button. Tapping within the input form displayed the software keyboard that participants used to respond to the simulated text messages. Pressing the “Send” button advanced the participant to the next page in the task flow, usually another text message. Each warning condition presented 29 unique random questions from the question list. Questions were never repeated within the same condition, and repeated randomly between conditions. In sum, each participant encountered 136 questions throughout the study.

Warning pages were designed to resemble the common features of severe weather warning messages displayed within the Android and iOS operating systems. Upon warning page load, the phone produced a tactile vibration consistent with the NWS WEA warning vibration, and thus different from the text message notification. Specifically, the phone emitted two long vibrations (800 ms each) separated by a brief (200 ms) pause.

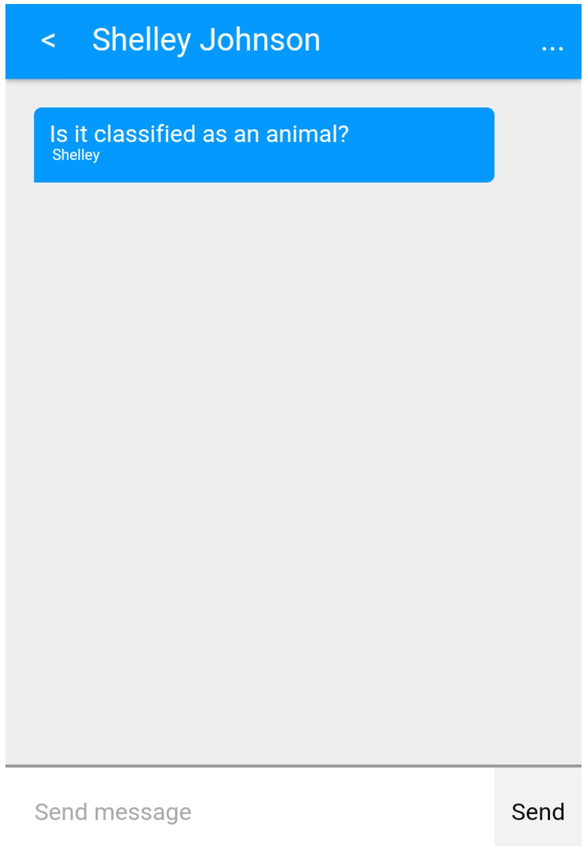

Figure 5. Text messaging page. This figure illustrates the design of the page that participants used to simulate sending a text message to a simulated recipient. Tapping "Send message" reveals the software keyboard on the smartphone.

The default warning page contained the following elements: a blue background image, a light grey dialogue box containing the warning content, the title "Emergency Alert", an "OK" button, and three sentences comprising a standard NWS WEA warning (see Figure 6). The first sentence indicated the type of hazard and the estimated time course of the hazard. The estimated time course was standardized for all participants to be six hours after the time the warning message was displayed. The second sentence indicated the recommended protective action one should take in response to the hazard. The final sentence instructed the recipient to check local media for more information. The message ended with a hyphen and the acronym NWS.

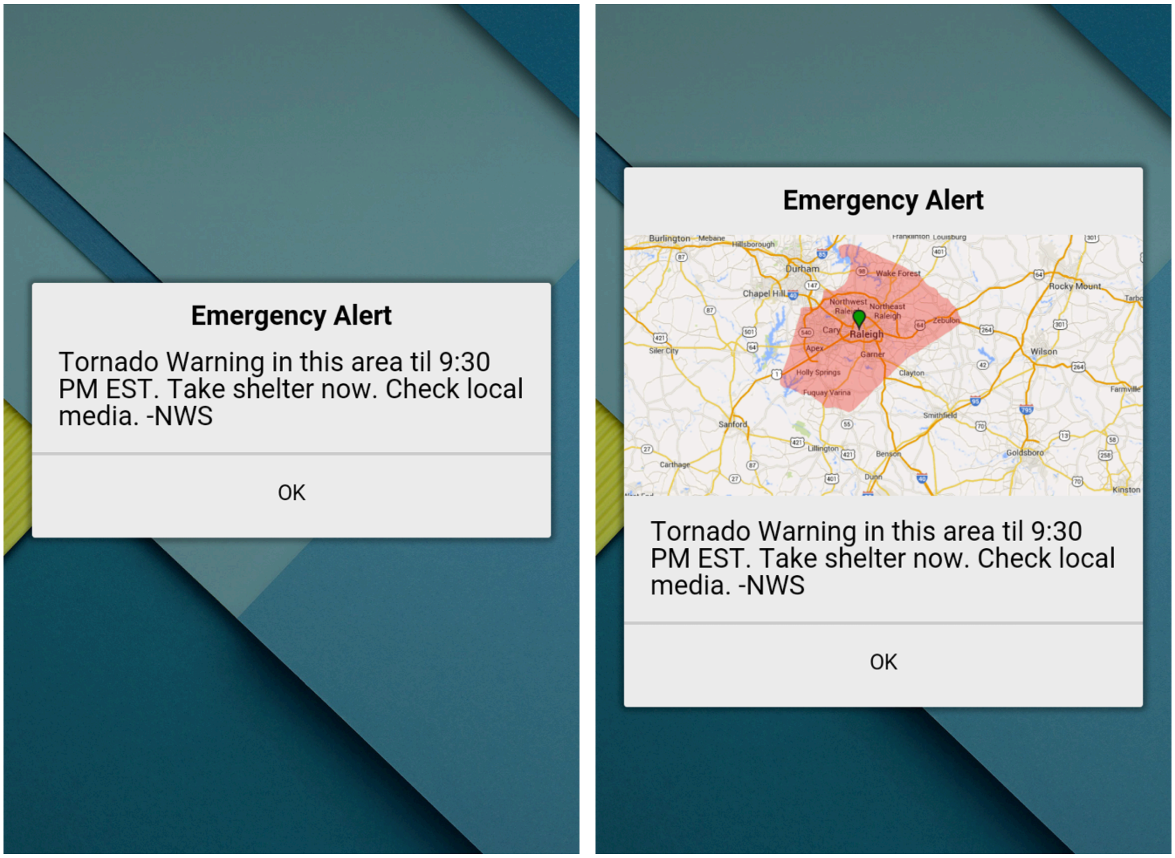

Figure 6. Default condition (on left) and map only condition (on right). This figure illustrates the primary design elements of the default warning, as well as the addition of an overhead map used in the map only condition.

Other aspects of warning pages varied between conditions. In addition to all elements of the default condition, the map only condition displayed a 768x387 pixel overhead map of Wake and Johnson counties (see Figure 6). Overlaid on the map were two graphical aids: a warning polygon and a location marker. The warning polygon covered all of Wake County in a semi-transparent red. The location marker was a green upside-down teardrop-shaped indicator, used commonly in overhead map programs to indicate one's approximate location. The location marker reflected the participant's actual location on campus.

The ratings only condition displayed all elements of the default condition, as well as indicators of hazard likelihood, hazard proximity, and hazard severity immediately below the message (see Figure 7). Ratings for each were indicated by a configuration of four squares arranged horizontally and surrounded by a grey border. The number of red squares indicated the actual rating for each indicator; the more red squares present, the higher the rating for that indicator. Hazard ratings were standardize for all participants to indicate a likelihood of three, a proximity of four, and a severity of three.

The map and ratings condition displayed all elements of the default condition, as well as the overhead map from the map only condition and the hazard ratings from the ratings only condition (see Figure 7). In sum, there were four unique warning conditions: the default condition, representing the NWS WEA warning as it is currently implemented (Condition A on the launcher page), a map only condition (Condition B), a ratings only condition (Condition C), and map and ratings condition (Condition D).

Questionnaires. An online survey tool was used to administer two questionnaires. The first questionnaire, referred to as the "Qualification Survey," was distributed to recruited participants to determine if they met the criteria for participation, as well as to obtain their contact information to schedule the follow-up laboratory session. The second questionnaire, referred to as the "Text Messaging Survey," was used during the laboratory session to administer instructions, tasks, and survey items to the participants. Both online surveys are described in further detail in the following paragraphs.

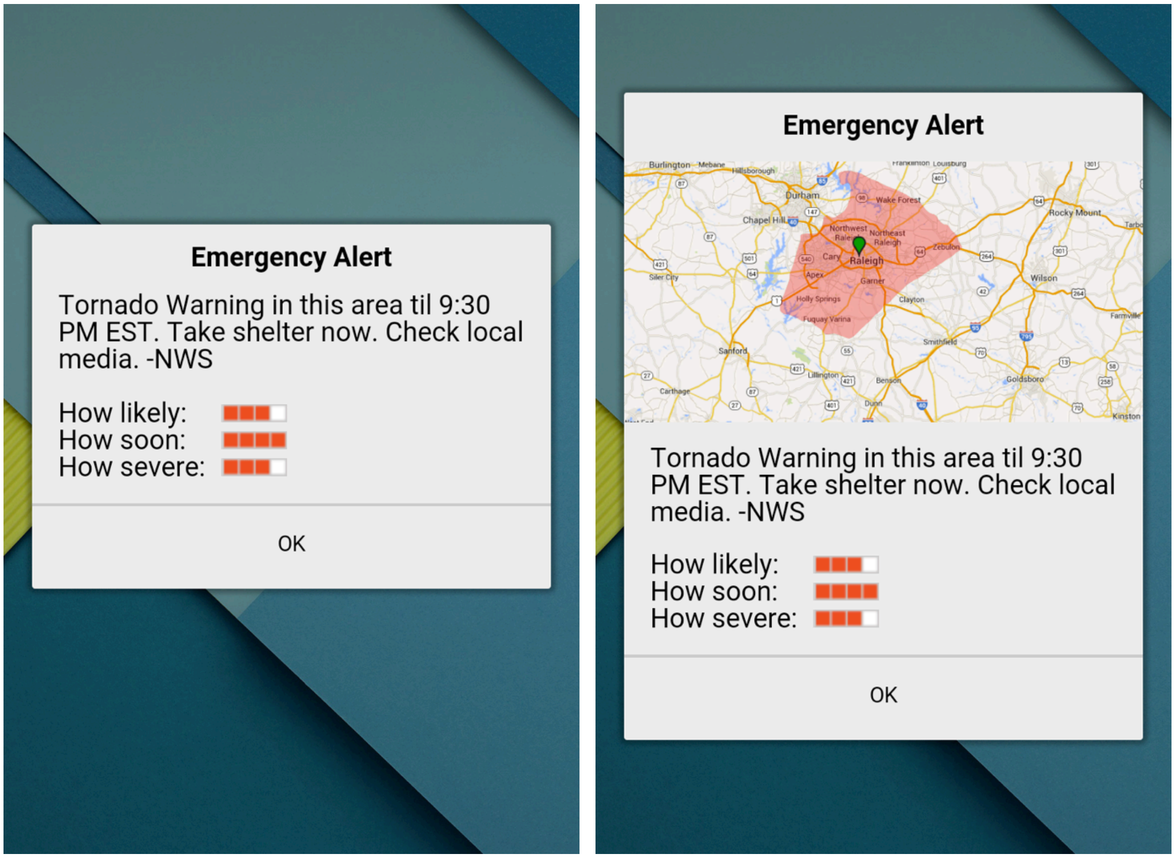

Figure 7. Ratings only condition (on left) and map and ratings condition (on right). This figure illustrates the appearance of the hazard rating information in the ratings only condition, as well as the appearance of the combined map and ratings condition.

The qualification survey contained four sections: demographic information, smartphone experience, reading comprehension ability, and color vision ability. The demographic information section contained five items. The first was an open-ended item for age, followed by multiple-choice items for gender, highest level of education attained, and racial or ethnic group. The final question asked participants to indicate their native language, with English and “Other, please specify:” as the only options.

The smartphone experience section contained three items. The first item asked participants to indicate if they owned a smartphone; response items were yes and no. If the participant responded in the affirmative, they were then prompted to specify what type of smartphone they owned. If the participant responded in the negative, they were asked to indicate if they had any experience with several common smartphone types.

The next section of the qualification survey was used to measure reading comprehension. A passage from the Nelson-Denny Reading Test (Brown, Fischo, & Hanna, 1993) was presented within the survey. Five multiple-choice questions pertaining to information provided in the passage were presented below the passage. The following section was used to administer the Ishihara Color Vision Test (Ishihara, 1993). A 17-plate version of the Ishihara test was used, all of which were presented in random order. For each of the 17 items, participants were instructed to type the number they saw into a text field, or type the letter "n" if they did not see a number. Altogether, there were 15 number and two non-number plates. Participants were excluded from the study if they did not score above 80% accuracy on the Ishihara test. After completing all sections of the qualification survey, participants were prompted to provide their email address to facilitate scheduling of the in-person laboratory session, then thanked for their participation. See Appendix B for the complete qualification questionnaire.

The text messaging survey was administered to the participant during the laboratory session. It was presented as a shortcut on the desktop of the computer labeled "TEXT MESSAGING SURVEY;" clicking the shortcut opened the survey in a Firefox web browser window. This survey contained three sections: introduction, experimental conditions, and conclusion questions. The introduction section prompted participants for their participant ID number, then provided instructions about the nature of the upcoming text messaging tasks. In addition, this section also contained a practice trial that was used to familiarize participants with condition assignment and the text-messaging web application. The practice trial page instructed the participant to use the phone to complete the practice condition using an assigned TQT item: a cat. The item was displayed in all capital letters as “A CAT”, and a picture of a cat was also displayed to aid in the text-messaging task. The practice trial page concluded with a yes or no question prompting the participant to indicate that they had completed the trial.

The experimental conditions section was used to administer the warning conditions in random order. This section was divided into four identical subsections, each corresponding to one of the four warning conditions. Each subsection contained three pages: condition assignment, emergency alert verification, and follow-up questions. The condition assignment page of each subsection instructed the participant to begin one of the experimental trials on the phone. The page also contained a TQT item, displayed as a word in all capital letters and accompanied by a picture of the item. The assigned TQT items were a baseball for Condition A, an apple for Condition B, a pencil for Condition C, and an eagle for Condition D. After verifying that they had completed the assigned text-messaging trial by answering a yes or no question, participants proceeded to the next page of the survey.

The emergency alert verification page contained one question asking the participant to indicate if they had encountered an emergency alert during the text-messaging trial. If the participant responded in the negative, they would continue to their next assigned condition. If the participant responded in the positive, they were directed to a page containing follow-up questions pertaining to the warning they experienced.

The follow-up question page contained twelve survey items to assess various aspects of the participant's warning experience. The first ten of these items were presented in a rating matrix. The participant was instructed to rate their agreement with each of the statements on a 5-point Likert scale of 1 (*strongly disagree*) to 5 (*strongly agree*). These items included statements concerning the validity of the warning, the severity of the warning, the perceived damage of the warning, the certainty of the warning, two measures of personalization of the risk perceived from the warning (family-centric and friend-centric), intention to take protective action, the urgency of the warning, the helpfulness of the warning, and the need for more information. Most of the items in this group were adapted from Casteel and Downing (2013). The friend-centric personalized risk, validity, urgency, helpfulness, and information-seeking items were modeled after Casteel and Downing's (2013) items and were developed to ascertain more specific information about the participant's perception of the warning itself. The final two items in this section were adapted from Hitt II et al. (2000), and elicited one's self-predicted and other-predicted warning response behavior. Participants completed these survey items four times: once for each warning condition. For the exact wording of each of these items, see Appendix C.

After completing all four experimental conditions, participants proceeded to the conclusion section of the questionnaire. This section contained two pages of items to assess participants' overall experience with and perceptions of several different weather events. The first part of this section contained a rating matrix and a list of the following weather events:

tsunami, tornado, extreme wind, hurricane, typhoon, flash flood, and dust storm (based on the weather events where the NWS deploys a warning). The matrix elicited participants' perception of the hazard of each of the events on a 5-point scale from 1 (*no hazard at all*) to 5 (*extremely hazardous*). The same list of weather events was presented in a second matrix, and required participants to indicate his or her prior experience with each event with a "Yes", "No", or "I don't know."

The second page of the final section of the questionnaire was focused specifically on the participants' prior tornado experience, and adapted from the questions used in Sharma & Patt (2012). The first item in this section asked participants to indicate how many tornados they had experienced previously. If the participant had not experienced any tornados, they would skip to item five. The second item asked participants to indicate how many tornado warnings they had received in the past. The third item asked participants to indicate their previous experience with how frequently tornados occur after receiving a warning. The fourth and final item assessed participants' perceptions of tornado severity in comparison to warnings they had previously received. See Appendix D for more details about this section of the questionnaire.

Working Memory Task. The shortened reading span task (Rspan; Oswald, McAbee, Redick, & Hambrick, 2015) was used to assess individual differences in working memory capacity. Complex span tasks typically involve the pairing of a task and an item to be remembered (Unsworth et al., 2005). The reading span task, initially developed by Daneman and Carpenter (1980), requires participants to read a sentence, indicate if the sentence was logical or not logical, and then view a letter that must be recalled later. Upon completion of the set, participants use a matrix of letters to indicate the order in which the letters were presented. Stimuli were presented electronically using the E-Prime 2.0 software (Psychology Software Tools, Pittsburgh, PA).

This implementation of the reading span task was entirely self-directed and thus required very little intervention from the researcher during its administration. First, participants practiced three components of the task: the memory component, the sentence-judging component, and then both components paired. Participants completed two sets of three practice trials for each. Importantly, the sentence-judging component practice was also used to record the participant's average time for the sentence-judging tasks. This average time was used to implement a personalized time limit, 2.5 *SD* above the average response time, for each participant in the final practice trial and in the full task itself. To conceal the true name of this task, the software shortcut was named "ABILITY TASK 1."

Once the participant completed all of the practice trials they began the full task. The current study implemented the shortened version of the automated Rspan task, which was developed reduce the time needed to administer the task (Oswald et al., 2015). The shortened version of this task contained three repetitions of each set size between four and six, in random order, for a total of 45 pairs. The full task also provided feedback regarding participant's sentence-judging performance. Participants were instructed to maintain an accuracy of 85% or greater. Combined with the 2.5 *SD* time limitation, these parameters were intended to ensure that appropriate speed and accuracy were being spent on the sentence judging task and not on rehearsing the letter series. Upon task completion, participants were directed to notify the moderator and await further instructions.

Attention Task. The sustained-attention-to-response task (SART; Robertson, Manly, Andrade, Baddeley, & Yiend, 1997) was used to assess attentional ability. SART is a go/no-go task requiring the participant to respond quickly to common non-targets and inhibit response to rarely occurring targets. The trials first displayed a fixation cross, followed by a digit (either a target or non-target), then a mask (the number sign), then a cue for the participant to respond (the digit zero). The primary metric of interest was the number of errors of omission, or failures to inhibit responses to the target stimuli. Stimuli were presented electronically using the E-Prime 2.0 software (Psychology Software Tools, Pittsburgh, PA). To conceal the true name of this task, the software shortcut was named "ABILITY TASK 2."

To familiarize participants with the nature of the task, a practice trial consisting of eight non-target stimuli and one target stimulus was administered. The target stimulus occurred approximately halfway through the practice trial. The implementation of SART used in the current research was programmed to administer three blocks of 45 stimuli, for a total of 135 stimuli; shortened from its original implementation of six blocks due to time constraints. Non-target stimuli consisted of numbers between one and nine, presented in a randomized order and separated by 500ms intervals. Each number was presented a total of five times per block. Target stimuli for all blocks was the number three, meaning there are a total of 15 targets across all three blocks; all other numbers in the range are non-targets. Participants used the spacebar to respond to the stimuli. A short rest period occurred between each block; participants were prompted to press any key on the keyboard when they were ready to proceed. Upon task completion, participants were instructed to notify the moderator and await further instructions.

Procedure

During recruitment, the experiment was referred to as a "Text Messaging Study." This initial description was intended to prime participants to focus on their smart phone before and during the study. Those who were initially recruited completed the qualification survey on their own time to determine their eligibility to participate in the laboratory experiment. Those who were not eligible were thanked for their participation and rewarded with course credit. Those who were eligible were contacted via email with instructions for scheduling the in-person laboratory session.

When participants arrived at the laboratory for their scheduled appointment, the researcher greeted them and escorted them into the room where the study was being conducted. The participant was then asked to read and complete the study consent form before the experiment could proceed. The moderator then administered a brief visual ability assessment. Participants were instructed to stand at a marking on the floor, situated nine feet in front of a standard Snellen chart posted on a nearby wall. Participants were instructed to read lines six through eight on the chart to demonstrate adequate visual acuity. If the participant failed to complete this measure, they were thanked for their participation and dismissed. After successfully completing the visual ability assessment, the participant was instructed to sit at the desk in front of the computer. The moderator then read a script aloud explaining the general proceedings of the study and the specific tasks to be completed, when appropriate.

After confirming that the participant was ready to begin the study, the moderator then instructed the participant to open a program labeled "ABILITY TASK 1", known to the moderator as the working memory task, and follow the instructions provided by the program. Participants were also reminded that they should feel free to ask questions of the moderator if they were confused at any point. Upon completion of the first ability task, participants were instructed to open a program labeled "ABILITY TASK 2", known to the moderator as the attention task. The two ability tasks typically required a total of 30 minutes to complete.

Upon completion of the ability tasks, the moderator provided instructions about the forthcoming text-messaging task, and explained that the computer survey would provide the instructions, tasks, and survey questions as necessary. The moderator explained that the primary task for the current study was a modified version of the Twenty Questions game taking place via a simulated text message conversation on the smartphone, then elaborated on the participant's role in the game as it pertained to the current study. The participant was informed that they would be assigned a Twenty Questions item for each text messaging trial, and that they should respond to text message questions as quickly and accurately as possible based on the item they were assigned. The moderator emphasized that all stimuli viewed on the smartphone were completely simulated and only for research purposes. The participant was then instructed to open the shortcut labeled "TEXT MESSAGING SURVEY" and follow the instructions as necessary.

Participants first completed a practice condition to familiarize themselves with the procedure of transitioning from the laptop to the smart phone and back. After the practice, participants completed each condition in a random order as assigned by the computer survey.

For each condition, the survey provided a Twenty Questions item and instructions to complete a specific condition using the smart phone. Participants would then pick up the smart phone, select the prescribed condition using the smart phone web application, and begin the text-messaging task. A surprise warning would occur approximately halfway through the text-messaging task. After completing the text-messaging task for the assigned condition, the smart phone web application would prompt the participant to return to the laptop, where they would respond to follow-up questions and receive the next condition assignment. This task flow was repeated until the participant had completed all four conditions.

After completing all four warning conditions, participants completed the conclusion section of the questionnaire, and would then notify the moderator that they had completed the survey. The moderator provided a debriefing statement explaining the true nature of the experiment and providing contact information for the primary investigator. Participants were thanked for their participation, informed about when they could expect to receive the course credit reward, and dismissed.

Results

The results section contains nine sections. The first section presents descriptive statistics for all demographic information and dependent variables. The following sections present relevant analyses for each of the six hypotheses.

Several variables were computed. For each participant, average response times of the five text messages immediately before and immediately after each warning were computed into two new variables. Thus, eight computed variables were created for each participant.

Descriptive Statistics

Seventy-four students (54 women, 20 men) participated in the study. The mean age of participants was 20.26 years (*SD* = 2.4) and ranged from 18 to 30 years. All participants had at least a high school diploma or GED, and only four participants were non-native English-speakers. All participants reported having experience with smart phones; sixty-one participants owned an Apple iPhone, twelve participants owned and Android Phone, and one participant owned a Windows Phone.

Several ability measures were also obtained. Reading comprehension was measured using a single passage from the Nelson-Denny Reading Test (Brown et al., 1993). Participants generally performed well on this task, with a mean accuracy rate of 93% (SD = 13%). Color vision was measured using a digital version of the Ishihara color-blindness test (Ishihara, 1993). Participants elicited high performance on this measure, with a mean accuracy of 96% (*SD* = 6%). Working memory was measured using the Shortened Reading Span task (Oswald et al., 2015); partial scores represent the participant's highest number of consecutive correct answers achieved, whereas total scores represent the total number of correct answers achieved. Attention was measured using the Sustained Attention to Response task (Robertson et al., 1997); scores represent the number of errors of omission committed over the entirety of the task. Descriptive statistics of the ability measures are presented in Table 1.

Hazard perception and warning perception items were recorded on a 5-point Likert scale, with higher ratings indicating greater agreement with the corresponding statement (see Appendix C for the exact wording of each item). Response times for the text-messaging task are presented in seconds. The before warning values are the average of the five text messages immediately preceding the warning; the after warning values are the average of the five text messages immediately following the warning. Descriptive statistics for the aforementioned dependent variables are presented in Table 2.

For each warning, participants indicated what behavior they might perform, and what behavior others might perform, in response to the warning. Self-predicted and other-predicted behavioral response items were presented as multiple-choice questions with three options: take shelter, prepare but don't take shelter, and do nothing. Frequencies for the behavioral prediction items are presented in Table 3.

General hazard perceptions of several different weather events were also obtained. General hazard perception was measured on a five-point scale, with higher ratings indicating a greater perceived hazard of the corresponding weather event. The relevant weather hazard, tornado, was rated as very hazardous on the scale ($M = 4.43$, $SD = .68$).

Prior experience with tornados was measured using several items: number of previously experienced tornados, number of previously received tornado warnings, and comparisons of tornado occurrence and severity given warning. Descriptive statistics of each of the aforementioned items are presented in Table 4.

Table 1

Descriptive Statistics of Ability Measures

	M	SD
Reading Comprehension	(93.0%)	(13.0%)
Color Vision	(96.0%)	(6.0%)
Working Memory (Partial)	12.35	7.96
Working Memory (Total)[a]	21.16	5.64
Attention[b]	4.97	11.62

Notes: [a] Possible scores range from 0-30. [b] Possible errors range from 0-135.

Table 2

Mean Perception Ratings and Response Times Across All Conditions

	Default		Map Only		Ratings Only		Map and Ratings	
	M	SD	M	SD	M	SD	M	SD
Hazard Perception								
In Area	4.16	.76	4.55	.55	4.28	.63	4.39	.86
Severe	4.11	.84	4.27	.73	4.39	.57	4.53	.67
Damage	3.82	.88	4.01	.85	4.20	.68	4.18	.88
Certain	3.42	.95	3.50	.98	3.88	.83	3.84	1.02
Loved Ones	3.54	1.18	3.76	1.11	3.92	1.03	3.95	1.18
Friends	3.61	1.08	3.96	.90	4.07	.87	4.14	1.01
Warning Perception								
Info Protect	2.85	1.32	3.01	1.24	3.27	1.21	3.45	1.28
Urgent	4.04	.85	4.19	.79	4.32	.74	4.35	.77
Helpful	3.66	1.13	3.92	.84	4.11	.69	4.18	.88
More Info	3.41	1.11	3.35	1.23	3.08	1.10	2.77	1.19
Text Messaging Task								
Before Warning	3.00	.62	3.04	.79	3.18	1.37	3.26	.78
Warning	6.55	3.20	6.86	3.76	8.87	5.69	9.12	4.99
After Warning	3.40	.82	3.38	.85	3.39	.76	3.68	1.25

Table 3

Response Frequencies to Self-Predicted and Other-Predicted Behavioral Response Items

	Default		Map Only		Ratings Only		Map and Ratings	
	N	(%)	N	(%)	N	(%)	N	(%)
Self-Predicted Behavioral Response								
Shelter	37	(50.0)	33	(44.6)	38	(51.4)	40	(54.1)
Prepare	23	(31.1)	30	(40.5)	30	(40.5)	21	(28.4)
Nothing	14	(18.9)	11	(14.9)	6	(8.1)	13	(17.6)
Other-Predicted Behavioral Response								
Shelter	39	(52.7)	29	(39.2)	34	(45.9)	42	(56.8)
Prepare	22	(29.7)	35	(47.3)	31	(41.9)	20	(27.0)
Nothing	13	(17.6)	10	(13.5)	9	(12.2)	12	(16.2)

Table 4.

Descriptive Statistics of General Weather Hazard Experience Items

	N	(%)
Previous tornados experienced		
0	37	(.50)
1-3	34	(.46)
4-6	3	(.04)
More than 6	0	(.00)
Previous tornado warnings		
0	4	(.05)
1-3	17	(.23)
4-6	17	(.23)
More than 6	36	(.49)
Tornado occurrence given warning		
Never	14	(.19)
Rarely	25	(.34)
Sometimes	24	(.32)
Often	6	(.08)
All of the time	5	(.07)
Tornado severity given warning		
Less severe	36	(.49)
Same severity	33	(.45)
More severe	5	(.07)

Hypothesis 1A

One-way repeated-measures analyses of variance were used to examine the effects of warning condition on participants' responses to the hazard perception items of the post-warning questionnaire. Because observations are not independent in repeated measures designs, an additional assumption of sphericity must be considered. Sphericity assumes that the conditions are different, and that the differences between those conditions vary in the same way (Field, 2013). In the event that sphericity was violated, additional corrections to the degrees of freedom are reported (Field, 2013).

For all of the following analyses, the within-subjects predictor variable was warning condition (default, map only, ratings only, map and ratings). Additionally, simple contrasts were used to compare the default warning condition to all other conditions. All significant main effects and contrasts for each of the six hazard perception items are reported below.

For the item assessing one's perception of the proximity to the hazard, Mauchly's test indicated that the assumption of sphericity had been violated, χ^2 (5) = 19.54, p < .01, therefore degrees of freedom were corrected using Hyunh-Feldt estimates of sphericity (ε = .87). A main effect of warning condition [F(2.62, 190.94) = 3.90, p < .05, partial η^2 =.05] revealed significant mean differences. When compared to the default warning using simple contrasts, the map only warning elicited significantly higher agreement that the hazard was near the participant's location [F(1, 73) = 12.64, p < .01, partial η^2 =.15]. The ratings only [F(1, 73) = 1.33, p = n.s.] and map and ratings [F(1, 73) = 2.48, p = n.s.] conditions were not significantly different from the default condition.

For the item assessing one's perception of the severity of the hazard, Mauchly's test indicated that the assumption of sphericity had been violated, χ^2 (5) = 26.37, $p < .01$, therefore degrees of freedom were corrected using Huynh-Feldt estimates of sphericity (ε = .83). A main effect of warning condition [$F(2.48, 180.70) = 5.23$, $p < .01$, partial $\eta^2 = .07$] revealed significant mean differences. When compared to the default warning using simple contrasts, the ratings only [$F(1, 73) = 5.96$, $p < .05$, partial $\eta^2 = .08$] and the map and ratings [$F(1, 73) = 10.30$, $p < .01$, partial $\eta^2 = .12$] warning conditions elicited significantly greater perceptions of hazard severity. The map only [$F(1, 73) = 1.51$, p = n.s.] condition was not significantly different from the default warning.

For the item assessing one's perception of the hazard's likelihood to cause damage, Mauchly's test indicated that the assumption of sphericity had not been violated, χ^2 (5) = 10.22, p = ns. A significant main effect of warning condition [$F(3, 219) = 4.12$, $p < .05$, partial η^2 =.05] revealed significant mean differences. When compared to the default warning using simple contrasts, the ratings only [$F(1, 73) = 8.65$, $p < .01$, partial $\eta^2 = .11$] and the map and ratings [$F(1, 73) = 6.12$, $p < .05$, partial $\eta^2 = .08$] warning conditions elicited significantly higher agreement that the hazard was likely to cause damage. The map only [$F(1, 73) = 2.12$, p = n.s.] condition was not significantly different from the default warning.

For the item assessing one's perception of the hazards certainty to occur, Mauchly's test indicated that the assumption of sphericity had not been violated, χ^2 (5) = 9.92, p = ns. A main effect of warning condition [$F(3, 219) = 6.10$, $p < .01$, partial $\eta^2 = .08$] revealed significant mean differences. When compared to the default warning using simple contrasts, the ratings only [$F(1, 73) = 10.52$, $p < .01$, partial $\eta^2 = .13$] and the map and ratings [$F(1, 73)$

$= 8.78$, $p < .01$, partial $\eta^2 = .11$] warning conditions elicited significantly higher perceptions of certainty that the hazard will occur. The map only [$F(1, 73) = .364$, p = n.s.] condition was not significantly different from the default warning.

For the item assessing one's perception of their own likelihood to contact their loved ones about the hazard, Mauchly's test indicated that the assumption of sphericity had been violated, χ^2 (5) = 15.21, $p < .05$, therefore degrees of freedom were corrected using Hyunh-Feldt estimates of sphericity ($\varepsilon = .93$). A main effect of warning condition [$F(2.78, 202.71) = 4.70$, $p < .01$, partial $\eta^2 = .06$] revealed significant mean differences. When compared to the default warning using simple contrasts, the ratings only [$F(1, 73) = 7.48$, $p < .01$, partial $\eta^2 = .09$] and the map and ratings [$F(1, 73) = 9.67$, $p < .01$, partial $\eta^2 =.12$] warning conditions elicited significantly higher likelihood of contacting one's loved ones about the hazard. The map only [$F(1, 73) = 2.85$, p = n.s.] condition was not significantly different from the default warning.

For the item assessing one's perception of their own likelihood to contact their friends about the hazard, Mauchly's test indicated that the assumption of sphericity had been violated, χ^2 (5) = 12.81, $p < .01$, therefore degrees of freedom were corrected using Huynh-Feldt estimates of sphericity ($\varepsilon = .94$). A main effect of warning condition [$F(2.81, 205.50) = 7.91$, $p < .001$, partial $\eta^2 = .10$] revealed significant mean differences. When compared to the default warning using simple contrasts, the map only [$F(1, 73) = 7.67$, $p < .01$, partial $\eta^2 = .095$], ratings only [$F(1, 73) = 12.62$, $p < .01$, partial $\eta^2 = .15$] and the map and ratings [$F(1, 73) = 15.89$, $p < .001$, partial $\eta^2 = .18$] warning conditions elicited significantly elicited significantly higher likelihood of contacting one's friends about the hazard.

In sum as depicted in Figure 8, the ratings only and map and ratings conditions elicited significantly different hazard perceptions from the default condition across all measures except the item assessing hazard proximity. Conversely, the map only condition was significantly different from the default condition only on the hazard proximity and contacting friends items. Taken together, these findings illustrate that differences in warning information were effective in eliciting differences in hazard perception.

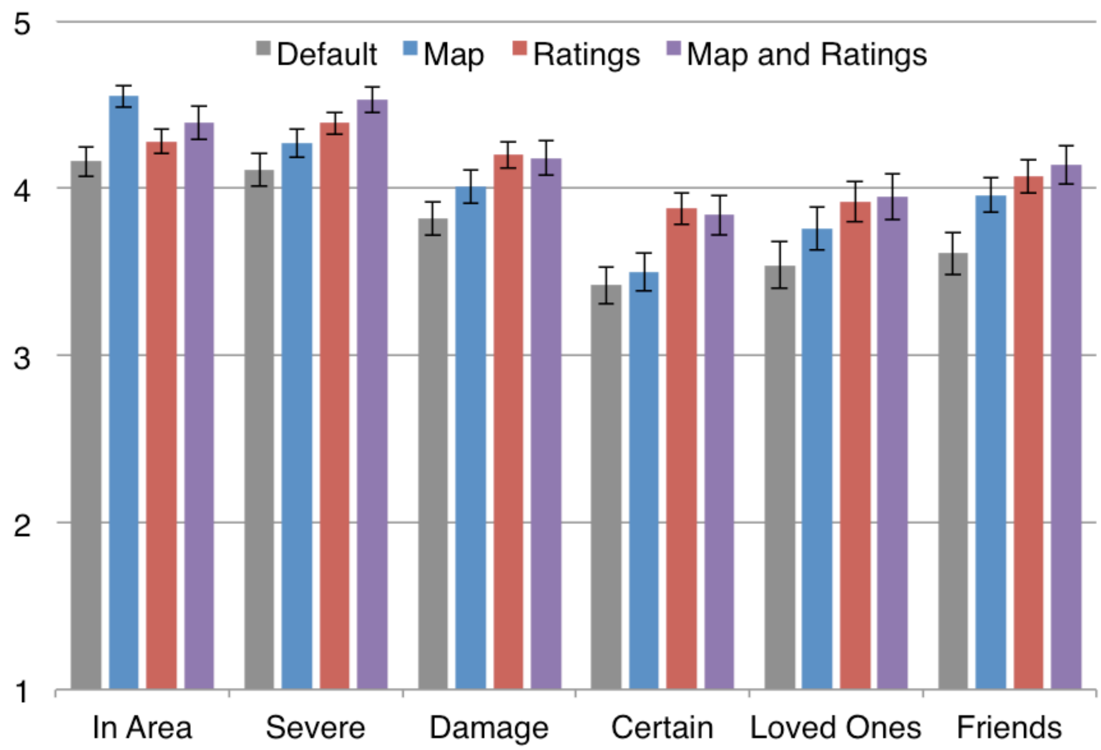

Figure 8. Mean agreement ratings for each of the hazard perception items across each condition. Error bars represent the standard error of each mean.

Hypothesis 1B

Similar to Hypothesis 1A, one-way repeated-measures analyses of variance were used to examine the effects of warning condition on participants' responses to the warning perception items of the post-warning questionnaire. For all of the following analyses, the within-subjects predictor variable was warning condition (default, map only, ratings only, map and ratings). Additionally, simple contrasts were used to compare the default warning condition to all other conditions. All significant main effects and contrasts for each of the six warning perception items are reported below.

For the item assessing one's perception of the warning information being useful for protecting oneself and others, Mauchly's test indicated that the assumption of sphericity had not been violated, χ^2 (5) = 6.15, p = ns. A main effect of warning condition [$F(3, 219) = 4.32$, $p < .01$, partial $\eta^2 = .15$] revealed significant mean differences. When compared to the default warning using simple contrasts, the ratings only [$F(1, 73) = 7.64$, $p < .01$, partial $\eta^2 = .10$] and the map and ratings [$F(1, 73) = 11.25$, $p < .01$, partial $\eta^2 =.11$] warning conditions elicited significantly higher agreement that the warning contained information usable for protecting oneself and others. The map only [$F(1, 73) = 1.16$, p = n.s.] condition was not significantly different from the default warning.

For the item assessing one's perception of the urgency of the warning, Mauchly's test indicated that the assumption of sphericity had not been violated, χ^2 (5) = 8.11, p = ns. A main effect of warning condition [$F(3, 219) = 3.11$, $p < .05$, partial $\eta^2 =.04$] revealed significant mean differences. When compared to the default warning using simple contrasts, the ratings only [$F(1, 73) = 5.96$, $p < .05$, partial $\eta^2 = .08$] and the map and ratings [$F(1, 73) = 5.56$, $p < .05$, partial $\eta^2 = .07$] warning conditions elicited significantly higher perceptions of warning urgency. The map only [$F(1, 73) = 1.50$, p = n.s.] condition was not significantly different from the default warning.

For the item assessing one's perception of the helpfulness of the warning, Mauchly's test indicated that the assumption of sphericity had been violated, χ^2 (5) = 12.69, $p < .05$, therefore degrees of freedom were corrected using Huynh-Feldt estimates of sphericity (ε = .93). A main effect of warning condition [$F(2.78, 202.74) = 6.22$, $p < .001$, partial $\eta^2 = .08$] revealed significant mean differences. When compared to the default warning using simple contrasts, the ratings only [$F(1, 73) = 9.08$, $p < .01$, partial $\eta^2 = .11$] and the map and ratings [$F(1, 73) = 11.82$, $p < .01$, partial $\eta^2 = .14$] warning conditions elicited significantly perceptions of warning helpfulness. The map only [$F(1, 73) = 4.88$, p = n.s.] condition was not significantly different from the default warning.

For the item assessing one's perception of needing more information before making a decision, Mauchly's test indicated that the assumption of sphericity had not been violated, χ^2 (5) = 7.95, p = ns. A main effect of warning condition [$F(3, 219) = 6.68$, $p < .001$, partial η^2 = .22] revealed significant mean differences. When compared to the default warning using simple contrasts, the ratings only [$F(1, 73) = 6.16$, $p < .05$, partial $\eta^2 = .08$] and the map and ratings [$F(1, 73) = 18.60$, $p < .001$, partial $\eta^2 = .20$] warning conditions elicited significantly elicited significantly lower agreement with needing more information from the warning. The map only [$F(1, 73) = .13$, p = n.s.] condition was not significantly different from the default.

In sum as depicted in Figure 9, the ratings only and map and ratings conditions elicited significantly different hazard perceptions from the default condition across all measures, whereas the map only condition was not significantly different from the default on any measures. However, these findings still illustrate that differences between the warning conditions elicit differences in warning perception.

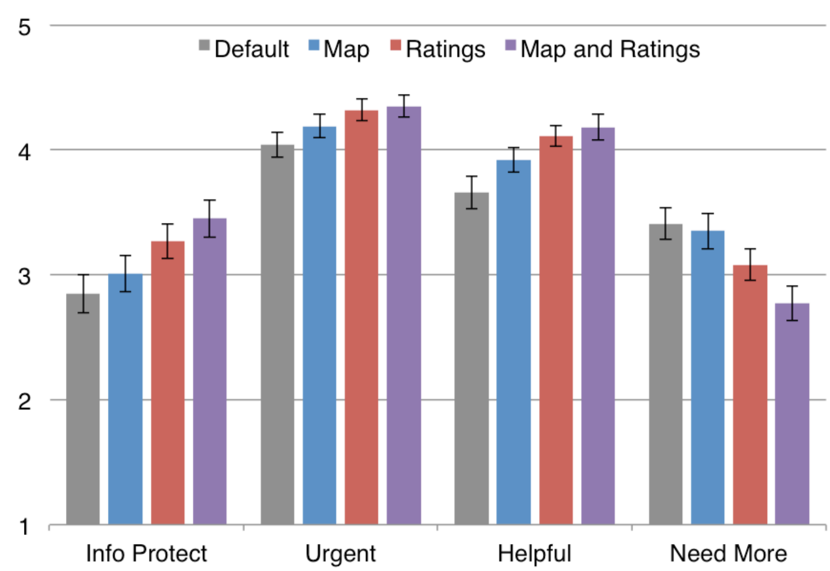

Figure 9. Mean agreement ratings for each of the warning perception items across each condition. Error bars represent the standard error of each mean.

Hypothesis 1C

To determine if there were differences in participant's self-predicted behavioral response and other-predicted behavioral response between warning conditions, a non-parametric Friedman test of differences among repeated measures was conducted. There were no significant differences between conditions for one's self-predicted behavioral response, χ^2 (3, N = 74) = 3.04, ns. Additionally, there were no significant differences between condition for one's prediction of other's behavioral response to the warning, χ^2 (3, N = 74) = 4.31, ns.

Hypothesis 2

A one-way repeated-measures analysis of variance was used to examine the effects of warning condition (default, map only, ratings only, map and ratings) on warning response time (as shown in Figure 10). Additionally, simple contrasts were used to compare the default warning condition to all other conditions. Mauchly's test indicated that the assumption of sphericity had been violated, χ^2 (5) = 13.86, $p < .05$, therefore degrees of freedom were corrected using Huynh-Feldt estimates of sphericity ($\varepsilon = .94$). A main effect of warning condition [$F(2.82, 206.04) = 9.80$, $p < .001$, partial $\eta^2 = .12$] revealed significant mean differences. When compared to the default warning using simple contrasts, the ratings only [$F(1, 73) = 15.35$, $p < .001$, partial $\eta^2 = .17$] and the map and ratings [$F(1, 73) = 16.91$, $p < .001$, partial $\eta^2 = .19$] warning conditions elicited significantly longer response times. The map only warning condition was not significantly different from the default warning. These findings support the hypothesis that different warning information would elicit differences in warning response time.

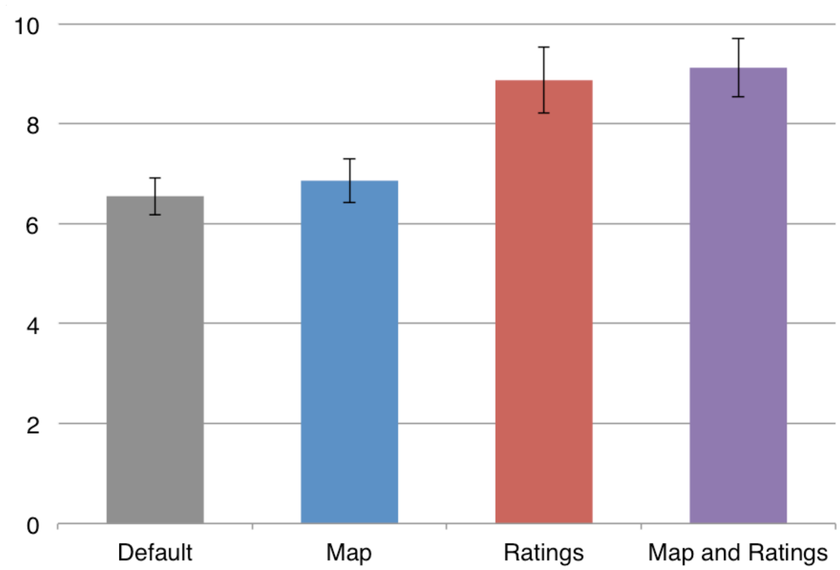

Figure 10. Mean response times (in seconds) for each warning condition. Error bars represent the standard error of each mean.

Hypothesis 3

A two-way repeated measures analysis of variance was used to examine the effect of warning presentation (before, after) on average text message response time for each warning condition (default, map only, ratings only, map and ratings). Mauchly's test indicated that the main effect of condition did not meet the sphericity assumption, χ^2 (5) = 11.32, $p < .05$, therefore degrees of freedom were corrected using Huynh-Feldt estimates of sphericity (ε = .95). A The analysis revealed a main effect of condition [F(2.84, 207.32) = 3.52, $p < .05$, partial $\eta^2 = .05$], indicating significant mean differences in text message response times between conditions. When compared to the default warning condition using simple contrasts, the map and ratings condition elicited significantly different text message response times [F(1, 73) = 7.84, $p < .01$, partial $\eta^2 = .10$]. The map only [F(1, 73) = .03, p = n.s.] and ratings only [F(1, 73) = .87, p = n.s.] conditions did not elicit significantly different text message response times compared to the default condition.

There was also a main effect of time [F(1, 73) = 35.67, $p < .001$, partial $\eta^2 = .33$], indicating that text message response times were significantly higher after warning presentation than before. There was not a significant interaction between condition and time [F(1, 73) = .73, p = n.s.]. These findings, shown in Figure 11, support the hypothesis that warning presentation leads to momentary cognitive resource usage.

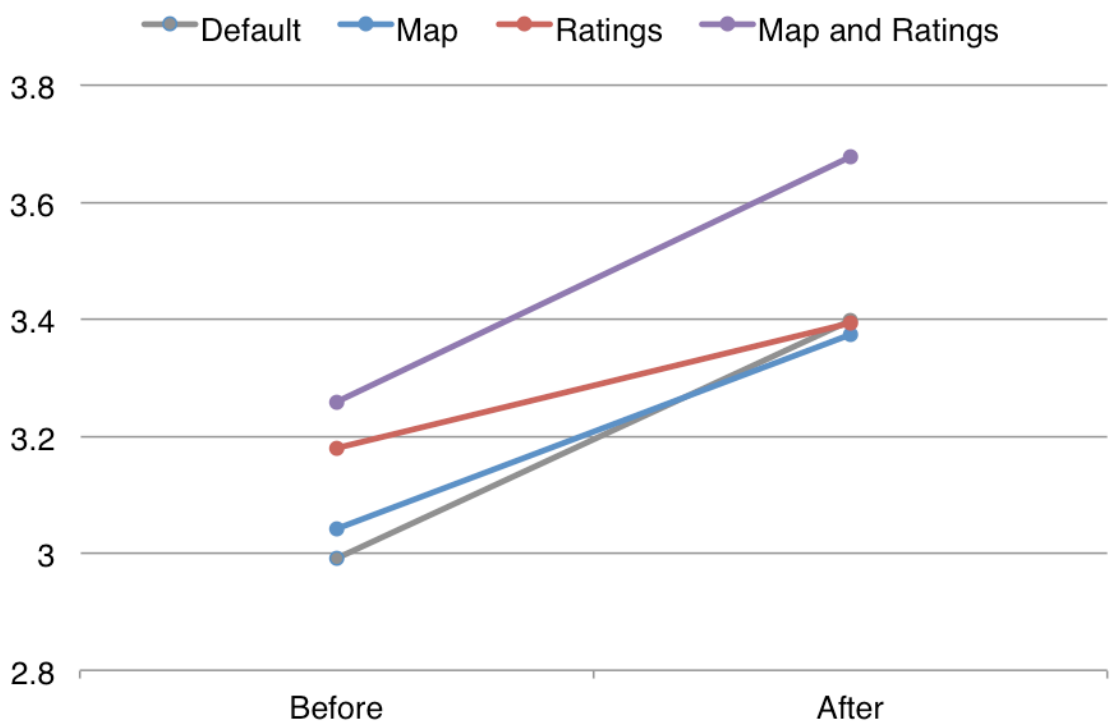

Figure 11. Mean text message response times (in seconds) before and after warning presentation in each condition.

Hypothesis 4

Correlation analyses were used to investigate the relationship between cognitive ability scores and warning response time. Working memory and attentional ability were revealed to have a significant negative relationship such that higher working memory scores were correlated with fewer attention errors. Results indicated that neither working memory ability nor attention ability were related to warning response time for any of the experimental conditions. Therefore, further regression analyses were not pursued. Correlation coefficients are presented in Table 5.

Table 5

Correlations Between Cognitive Abilities and Warning Response Times

	1	2
Working memory	--	
Attention	-.24*	--
Default	-.03	-.09
Map Only	.09	.03
Ratings Only	.11	.01
Map and Ratings	.18	-.06

Note: $*p < .05$

Hypothesis 5

Correlation analyses were used to investigate the relationship between cognitive ability scores and average text message response time immediately before and after warning presentation. Results indicated that neither working memory ability nor attention ability were related to text message response time before or after warning presentation. Therefore, further regression analyses were not pursued. Correlation coefficients are presented in Table 6.

Hypothesis 6

Nonparametric correlation analyses were used to investigate the relationship between participants' tornado hazard perception, previous tornado experiences, and ratings of hazard perception, warning perception, and predicted behavioral response for each condition.

A number of significant relationships were revealed for responses to the hazard perception scale items. In the default condition, more previously experienced tornados was associated with lower ratings of severity, and more previously experienced warnings were associated with lower ratings of certainty.

Table 6

Correlations Between Cognitive Abilities and Mean Text Message Response Time

	1	2
Working memory	--	
Attention	-.24*	--
Default Condition		
Before Warning	-.10	-.08
After Warning	-.09	-.03
Map Only Condition		
Before Warning	-.02	-.02
After Warning	-.16	-.1
Ratings Only Condition		
Before Warning	.10	-.06
After Warning	-.16	.18
Map and Ratings Condition		
Before Warning	-.02	-.08
After Warning	-.05	-.13

Note: $*p < .05$

In the map only condition, a more hazardous general perception of tornados was associated with greater agreement that the tornado was proximal to one's location. One's experience that tornados typically occur after warning was associated with higher ratings of severity and greater intent to contact one's friends about the storm. One's prior experience that tornados are typically more severe than indicated by a warning was associated with higher severity ratings in the experimental sessions. Correlations for the default and map only conditions are shown in Table 7.

In the ratings only condition, a more hazardous general perception of tornados was associated with greater perceptions that the tornado will cause damage. In addition, more previously experienced warnings were associated with lower agreement that the tornado was proximal to one's location. One's experience that tornados typically occur after warning was associated with a greater intent to contact one's loved ones about the storm.

Table 7

Correlations Between Previous Tornado Experiences and Hazard Perception Ratings (Default and Map Only Conditions)

	General hazard rating	Previous experience	Previous warnings	Occurrence given warning	Severity given warning
Default					
InArea	.06	.06	-.03	.15	.20
Severe	.04	-.25*	-.2	.01	.08
Damage	.00	-.10	-.17	-.03	.04
Certain	-.17	-.04	-.27*	.07	.19
Loved Ones	.06	.01	-.15	.12	.15
Friends	.02	-.08	-.19	.08	.08
Map only					
InArea	.23*	.03	-.02	.07	-.01
Severe	.22	.11	.07	.27*	.25*
Damage	.15	.04	.08	.22	.18
Certain	.10	.11	-.13	.19	.21
Loved Ones	.14	.12	-.01	.21	.18
Friends	.07	.14	.07	.23*	.19

Note: *$p < .05$

In the map and ratings condition, a more hazardous general perception of tornados was associated with greater ratings of severity, likelihood to cause damage, certainty that the storm will occur, and intent to contact one's loved ones. Correlations for the ratings only and map and ratings conditions are shown in Table 8.

Taken together, the above findings do not seem to reveal any meaningful patterns. Significant relationships were generally not consistent across conditions or across scale items. In light of these findings, further regression analyses were not conducted.

Table 8

Correlations Between Previous Tornado Experiences and Hazard Perception Ratings (Ratings Only and Map and Ratings Conditions)

	General hazard rating	Previous experience	Previous warnings	Occurrence given warning	Severity given warning
Ratings only					
InArea	.12	-.13	-.28*	.05	-.20
Severe	.07	.01	-.03	.23	-.12
Damage	.27*	.01	-.17	.11	-.03
Certain	.07	.10	-.17	.17	-.11
Loved Ones	.22	.07	-.15	.26*	.05
Friends	.11	-.05	-.22	.03	.02
Map and Ratings					
InArea	.16	.14	.09	.06	.19
Severe	.28*	.06	.04	.07	.04
Damage	.28*	.09	.02	-.03	.00
Certain	.24*	.10	-.05	.13	.13
Loved Ones	.24*	-.02	.10	.18	.12
Friends	.17	.00	.11	.14	.10

Note: *$p < .05$

Significant relationships for the warning perception items were also revealed. In the default condition, a greater number of previously experienced warnings was associated with lower ratings of warning urgency. One's experience that tornados typically occur after warning was associated with higher ratings of the warning's protective value and helpfulness.

In the map only condition, a more hazardous general perception of tornados was associated with greater ratings of warning urgency. A greater number of previously experienced warnings was associated with lower ratings of warning urgency. One's experience that tornados typically occur after warning was associated with higher ratings of the warning's protective value. In the ratings only condition, a greater number of previously experienced warnings was associated with lower ratings of warning urgency. Additionally, one's experience that tornados typically occur after warning was associated with lesser need of more information.

In the map and ratings condition, a more hazardous general perception of tornados was associated with greater ratings of warning urgency. Taken together, as shown in Table 9, the above findings seem to suggest that one's urgency rating was the most sensitive to previous experience from this set of scale items, eliciting a number of correlations to general hazard rating and previously experienced warnings.

Table 9

Correlations Between Previous Tornado Experiences and Warning Perception Ratings

	General hazard rating	Previous experience	Previous warnings	Occurrence given warning	Severity given warning
Default					
Info Protect	.05	.06	.00	.28*	-.09
Urgent	.12	-.11	-.24*	-.06	-.03
Helpful	-.05	.01	-.08	.30**	-.02
More Info	.02	-.11	-.06	-.09	-.07
Map only					
Info Protect	.04	.10	-.01	.23*	.07
Urgent	.33**	.05	-.24*	.02	-.02
Helpful	.03	.07	-.01	.18	-.12
More Info	.11	-.02	-.11	-.09	-.22
Ratings only					
Info Protect	-.02	.12	-.07	.03	-.13
Urgent	.08	-.04	-.28*	-.01	-.06
Helpful	.10	.15	-.14	.20	-.08
More Info	.03	-.14	.15	-.24*	.04
Map and Ratings					
Info Protect	.02	.17	.03	.08	-.04
Urgent	.31**	.08	-.02	.18	-.08
Helpful	.23	.05	.11	.20	.13
More Info	-.17	-.03	-.03	.19	.10

Note: $*p < .05$, $**p < .01$

The predicted behavioral response measures revealed an interesting pattern of findings. Across all four conditions, one's previous experience that tornados typically occur after warnings was significantly related to whether protective action would be taken. The same pattern was revealed for other-predicted behavior except in the default condition. Additionally, one's experience that tornados are typically more severe than indicated by a warning was associated with predicting that others would take protective action. Taken together, as shown in Table 10, these findings suggest the importance of previous experience of tornado occurrence in one's decision to take protective action.

Table 10

Correlations Between Previous Tornado Experiences and Self or Other-Predicted Behavioral Responses

	General hazard rating	Previous experience	Previous warnings	Occurrence given warning	Severity given warning
Default					
Self	-.08	.22	.00	.26*	.05
Other	-.05	.07	-.12	.18	.00
Map Only					
Self	.03	.18	.09	.26*	.09
Other	.09	.07	-.05	.25*	-.17
Ratings Only					
Self	.02	.15	-.01	.33*	-.09
Other	-.09	.19	-.11	.33**	.30*
Map and Ratings					
Self	.08	.17	.20	.28*	.18
Other	-.05	.20	.19	.24*	-.04

Note: *p < .05, **p < .01

In light of the findings above, several repeated-measures analyses of variance were conducted as follow-up analyses. For analyses concerning self- and other-predicted behavioral response, the response options were coded as numbers and treated as an ordinal scale of protective action such that higher numbers on the scale represent more protective action being taken (in this case, taking shelter). The analysis was conducted in this manner to conservatively examine any relationships while preserving the repeated measures nature of the data.

A repeated measures analysis of variance was used to examine the effect of previous tornado experience on self-predicted behavioral response. In this analysis the within-subjects factor was condition (default, map only, ratings only, map and ratings) and the between-subjects factor was one's experience of tornado occurrence given warning. The analysis revealed a between-subjects main effect of previous tornado experience [$F(4, 69) = 4.15$, $p < .01$, partial $\eta^2 = .19$], indicating significant mean differences in self-reported behavioral response for different experiences of prior tornado occurrence. Post-hoc analysis revealed that those who never experienced tornados after warning ($M = 1.98$, $SD = .79$] elicited significantly lower behavioral responses than those who experienced tornados sometimes [$M = 2.54$, $SD = .60$] and those who experienced tornados often [$M = 2.708$, $SD = .56$]. There was not a main effect of condition [$F(3, 207) = .48$, p = ns] or a significant interaction effect [$F(12, 207) = .28$, p = ns].

A repeated measures analysis of variance was also used to examine the effect of condition (within-subjects) and previous tornado experience (between-subjects) on other-predicted behavioral response. The between-subjects main effect of previous tornado experience approached significance [$F(4, 69) = 2.44$, $p = .055$]. There was not a within-subjects effect of condition [$F(3, 207) = .96$, p = ns.] nor an interaction effect [$F(12, 207) = .43$, p = ns.].

A final repeated measures analysis of variance was conducted to examine the effect of condition (within-subjects) and number of tornado warnings previously experienced (between-subjects) on ratings of warning urgency. The between-subjects main effect of tornado warnings previously experienced was not significant [$F(4, 69) = 2.35$, p = ns.]. There was not a within-subjects effect of condition [$F(3, 210) = .95$, p = ns.] nor an interaction effect [$F(9, 210) = .94$, p = ns.].

Discussion

This research investigated the impact of differences in warning information and in individuals across a variety of measures, and revealed a number of interesting findings. All hazard perception and warning perception items elicited significantly different ratings across warning conditions, supporting Hypotheses 1A and 1B. Specifically, the ratings only and map and ratings conditions elicited more favorable responses than the default condition on almost every measure. Both the ratings only and map and ratings conditions were different from the default in that they presented information indicating the certainty, time course, and severity of a hypothetical tornado. Participant's perceptions of the severity, likelihood of damage, and certainty of the hypothetical tornado were higher when the aforementioned information was present. These findings suggest that participants were able to comprehend the information, and that it influenced their appraisal of the hazard, consistent with the information processing stage of C-HIP (Laughery & Wogalter, 2006). Furthermore, existing research previously indicated that the provision of additional information regarding the strength of a weather event (Hitt II et al., 2000) and the uncertainty of the event (Sharma & Patt, 2012) were helpful in fostering more favorable warning responses, and indeed the current research supports this notion.

The incidence of significantly longer response times for warnings with additional information supported Hypothesis 2. Consistent with Hypotheses 1A and 1B, these differences were evident when comparing the default condition to the ratings only and map and ratings condition. Within the information processing stage of C-HIP, once a warning has attracted attention it must garner sustained attention long enough to allow for processing (Laughery & Wogalter, 2006). In the context of this research a longer response time would suggest that additional processing is taking place, and is therefore a favorable outcome. Although time is often scarce in severe weather scenarios, a few more seconds spent processing warning information may more quickly inspire the correct protective action compared to a shorter, less informative warning, which might conversely inspire one to seek additional information elsewhere and therefore delay taking action.

Both in terms of perceptual responses and response time, the map only condition elicited fewer significant differences from the default condition, only in regards to perceptions of the location of the hypothetical tornado and one's intention to contact their friends about the tornado. That the map only condition elicited greater agreement in the proximity of the hypothetical tornado relative to one's location is logical considering that the map displayed both an indicator of one's location as well as the warning polygon meant to indicate the areas affected by the weather event. That the map only condition elicited differences in one's intention to contact their friends but not loved ones is perhaps best explained by the fact that the sample consisted entirely of students, whose friends are likely closer to their location than their loved ones when on campus where the research was conducted. Casteel and Downing (2013) similarly found that the provision of a map did not elicit differences in most of the same perceptual measures used in the current research nor did it elicit differences in response time. The current research replicates these findings, and qualifies them in the context of more favorable warning responses elicited by the two other warning designs. Taken together, these findings seem to suggest that the provision of a strictly topographical map is likely not enough to change one's perception a weather event, and presumably not likely to change one's warning response either. However, it is possible that the right combination of information has not yet been discovered. Implementing features of more successful warning maps, such as cyclone warning maps that include visual representations of the storm's potential path across the map (Radford et al., 2013), may warrant further investigation.

Hypothesis 3 was also supported by the main effect of time, indicating that text message response times immediately after warning presentation were significantly longer than text message response times before the warning. These findings suggest that the presentation of a warning seems to have a temporary effect on one's attentional ability, possibly because the warning is still being processed even as participants continued the task. Poor sustained attention task performance following a severe natural hazard was found in Helton and Head's (2012) research, though their research was conducted before and after an actual earthquake rather than a hypothetical hazard. Still, these findings suggest that even the incidence of a warning has temporary cognitive impacts, which could be detrimental in hazardous scenarios like severe weather events and natural disasters.

The absence of differences on participant's ratings of self-predicted and other predicted behavioral responses are, in some ways, not surprising. One's behavioral response to a warning is typically not made in isolation. C-HIP indicates that environmental stimuli also serve as an input into the information processing stage that ultimately results in one's warning response (Wogalter, 2006). For a severe weather event, environmental stimuli such as observable weather conditions and the behaviors of other people certainly factor into one's behavioral response. Neither of these contextual stimuli were present in the testing environment: a windowless room with only the moderator and participant present. A controlled environment is both a hallmark and, in this case, a consequence of laboratory research. Existing research has acknowledged this limitation, and some studies have tried to provide supplementary context to participants. One study utilized brief vignettes to provide context about recent false alarms and the current weather conditions (Hitt II et al., 2000). Another study utilized a virtual reality display to investigate the effects of various environmental factors of hallways, such as lighting and corridor size, in an emergency evacuation scenario (Vilar, Rebelo, Noriega, Teles, & Mayhorn, 2013). Virtual reality displays continue to become more available and accessible, and using them to study the impact of simulated ambient weather conditions seems a worthy application of such technology.

Furthermore, the item used to measure self- and other-predicted behavioral response was rather limited in its response choices, offering choices for taking shelter, preparing but not taking shelter, and doing nothing. Certainly, there are other behavioral responses that one could make upon receiving a severe weather warning, such as relocating or seeking more information. An open-ended response item might have been beneficial in revealing important nuances in one's predicted behavioral response.

Hypotheses 4 and 5, those concerned with individual differences in working memory and attentional ability and their impacts on warning response time and text message response time respectively, did not reveal any significant differences. These findings are qualified by the fact that the sample demonstrated generally good performance on the cognitive measures: there was not a great deal of variance in either working memory ability or attentional ability. This is not particularly surprising considering that the participants were a sample of the psychology student population at a university, a population whose abilities are likely more similar than different. Further, selection bias is likely when employing the convenience sampling methods used in the current research. Existing research has also acknowledged that undergraduate student samples are more often outliers than representative of the general population (Henrich, Heine, & Norenzayan, 2013). However, investigating the influence of cognitive abilities on warning perception and response is still of importance. Future research seeking to explore individual differences in cognitive abilities as they pertain to warning response should consider sampling from multiple populations to ensure a wider range of cognitive abilities are represented. Certainly, individuals outside of educational institutions may exhibit different cognitive strengths and weaknesses. Further, studying the impact of declining cognitive functioning in older adults (Mayhorn, 2005), or differing abilities in other sensitive populations, on warning response will serve to vet the effectiveness of new warning designs in suboptimal circumstances.

Analyses for Hypothesis 6 were not ideal, but nonetheless interesting. Although it is disappointing that most of the beliefs, attitudes, and experience items did not reveal significant relationships, the finding that more frequent tornado experience following warning (and thus fewer false alarms) was associated with higher ratings of taking protective action is notable, and consistent with the influence of false alarms on warning response (Sharma & Patt, 2012). The role of prior experiences with severe weather events is another key receiver characteristic within the C-HIP framework. Existing research supports the association between previous experience and disaster response on an individual level (Lindell & Perry, 2004; Sharma & Patt, 2012). A similar association has been observed at the community level: communities that have experienced the same kind of disaster numerous times, or in recent memory, are typically more deliberate in their preparation for such hazards (Fritz, 1961).

That most of the other measures did not elicit significant findings is likely attributable to a few factors. Some participants experienced difficulties comprehending the previous tornado and warning experience questions, and thus may not have answered accurately. In addition, the distribution of responses to previous experience items was positively skewed, with most participants reporting experiencing tornados “rarely” or “sometimes” after warning. Future research should seek to recruit participants with more variation in their prior experience with hazardous weather to better investigate their impact on warning response. Further, the limited response choices for the previous experience and behavioral response measures, adapted from existing research, were not ideal for the intended analyses. Future research may benefit more from presenting items about previous experience and behavioral response as open-ended questions and coding the responses after the fact.

The current research is significant to the disaster warning literature for several reasons. Very little laboratory research has been conducted on the topic of severe weather warnings. The vast majority of the work in this area has centered on case studies and surveys after actual severe weather events (Balluz et al., 2000; Helton et al., 2013; O'Brien & Shreeves, 2013; Sharma & Patt, 2012; Sherman-Morris, 2013; Shreeves & O'Brien, 2013). It is also among the first experimental studies to investigate disaster warnings through the lens of the Communication-Human Information Processing (C-HIP) model, and the first to do so for severe weather warnings in particular. Furthermore, this is the first study to evaluate the smartphone implementation of the National Weather Service's WEA warnings.

There were other limitations to this research in addition to those mentioned above. The text messaging task was somewhat contrived due to technical limitations in the apparatus used. Though it was designed to simulate the pace and engagement of a conversation, the actual data more closely resembles responses on the SART task than that of a thoughtful conversation. The limited means of responding and the lack of intelligent and deductive questioning that usually characterize the Twenty Questions Task also lessen its realism somewhat. A more competent programmer could easily implement the logic of the Twenty Questions Task into the text messaging protocol utilized in the current research; future research may also seek to include a short delay between messages to better simulate the pacing of a conversational exchange. Furthermore, one could argue that participants in this experiment learned to expect a warning after their first or second experimental trial, further reducing its realism. Certainly, warnings in the real world do not occur quite so frequently, nor do we typically expect them. Future research could account for this by implementing a between-subjects design to ensure that each participant only sees one warning, thus preserving the element of surprise.

It is also worth acknowledging that many of the smaller details across the four warning conditions remained the same for all participants, when in reality that may not be the case. For example, the time course of the warning was a standard six hours for all participants. Studying the impacts of a shorter or longer time course may be fruitful for future study. Additionally, information provided by the certainty, time course, and severity ratings was the same across the two conditions that implemented them. However, the hazard ratings allow for an additional level of granularity for manipulation. Varying the values for each of the three ratings would be an interesting avenue for future study, especially as they relate to the perceptual measures used in the current research.

Finally, the modifications made to the warning stimuli were implemented according to the programming capabilities of the researcher. Although the modifications were chosen for their potential viability, it is uncertain whether these modifications would be technically feasible for the NWS to implement as they were in this study. However, considering the favorable results achieved when implementing visual indicators of weather event certainty, time course, and severity, it is this researcher's belief that these elements warrant consideration for implementation in WEA warnings. If these elements are not feasible using current technology, one might hope that technological innovation would eliminate those limitations sooner rather than later.

Future research should be directed at further exploring the efficacy of smart phone notifications as a warning channel, particularly for disaster warnings. Although notifications from the National Weather Service are already in use, it is possible that these warnings are not taking full advantage of the interactivity and intimacy of an individual's smart phone. For example, a recent effort by the Berkeley Seismology Lab developed a phone application called MyShake that utilizes the phone's hardware sensors to detect and report seismic activity associated with earthquakes (Kong, Allen, Schreier, & Kown, 2016). In the future, the application will also serve as a warning channel, using the same crowd-sourced data to facilitate earlier warnings to those who might be in danger (Kong et al., 2016). In addition, the increasing importance of social media, and its implications for influencing individual and group behavior, should be further explored in the context of warnings and disaster scenarios (O'Brien & Shreeves, 2013).

In sum, the current research serves to illustrate how the numerous capabilities of smart phones can be utilized to effectively communicate warnings in disaster scenarios. Given the proliferation of smart phones, and mobile technology in general, it is possible that such communication methods may actively supplement existing warning systems in developed nations. In doing so, it might be possible to maximize the number of lives saved and minimize the losses that occur amidst disaster situations.

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APPENDICES

Appendix A

Question List for the Twenty Questions Task (TQT)

1. Is it classified as an animal?
2. Is it classified as a vegetable?
3. Is it classified as a mineral?
4. Is it alive or dead?
5. Is it a single homogenous substance?
6. Does it have moving parts?
7. Is it manufactured?
8. Is it decorative?
9. Is it functional?
10. Is it disposable?
11. Is it associated especially with entertainment?
12. Is it associated with sports?
13. Is it associated with transportation?
14. Is it associated with communications?
15. Is it associated with education?
16. Is it associated with business?
17. Is it found on Earth?
18. Do people buy it (commonly)?
19. Does it cost less than $100?
20. Does it have writing on it?
21. Is it used by the police?
22. Can you put something into it?
23. Does it have sound?
24. Is it smaller than a golf ball?
25. Does it have pairs?
26. Does it have a specific color?
27. Is it commonly found near water?
28. Is it a mammal?
29. Is it electronic?
30. Does it have long legs?
31. Is it consumable?
32. Is it commonly found in a shop?
33. Does it have sound?
34. Is it commonly found in a human body?
35. Is it something you can wear?
36. Is it made of plastic?
37. Does it have a hard shell?
38. Does it burn?
39. Is it commonly found in cities?

40. Is it tall?
41. Is it completely white colored?
42. Does it weigh more than 2000 pounds?
43. Is it a body part?
44. Does it require specific knowledge to use it?
45. Do you use it with a computer?
46. Does it make something move?
47. Does it shine?
48. Does it have a backbone?
49. Does it have fur?
50. Does it weigh less than 2 pounds?
51. Is it a carnivore?
52. Is it commonly found in grassland?
53. Does it have teeth?
54. Can it swim?
55. Is it a domesticated animal?
56. Does it have a tail?
57. Can it fly?
58. Is it commonly found in mountains?
59. Is it used to record an event?
60. Is it an insect?
61. Is it something you bring along?
62. Is some part of it made of wood?
63. Can you order it at a restaurant?
64. Is it round shaped?
65. Is it soft?
66. Is it commonly found in bedrooms?
67. Does it produce heat?
68. Do people use this daily?
69. Is it a type of fruit?
70. Is it flexible?
71. Is it commonly found above ground?
72. Does it contain liquid?
73. Is it made of stone?
74. Do people eat it?
75. Is it connected to a wire?
76. Is it made of metal?
77. Does it use numbers?
78. Does it display information?
79. Is it more valuable than silver?
80. Is it hard?
81. Can it be stolen?
82. Is it made of glass?

83. Is it completely brown colored?
84. Is it organic?
85. Does it dig holes?
86. Is it smaller than a car?
87. Does it have legs?
88. Can you control it?
89. Do you find it in the sky?
90. Does it have eyes?
91. Is it used during meals?
92. Is it mechanical?
93. Does it produce light?
94. Is it solid?
95. Is it used to carry things?
96. Does it have a memory?
97. Is it completely black colored?
98. Do liquids pass through it?
99. Would you use it in the dark?
100. Does it change colors?

Appendix B

Qualification Survey

This is the first part of a two-part experiment. In order to receive credit for your participation, you must complete this survey as well as the in-person lab study that follows. If you do not participate in the lab study, you will not receive credit for your participation in this survey. Completing this survey and the lab study will earn you two credits (1 hour). This survey is a prerequiste to experiment #2008. Please complete all of the tasks and questions to the best of your ability. This survey should take about 15 minutes to complete.

What is your age (in years)? ____________________

Please indicate your gender.
- ❍ Female
- ❍ Male
- ❍ Other (Please specify) ____________________

What is the highest level of education you have completed?
- ❍ Less than High School
- ❍ High School / GED
- ❍ Some College
- ❍ 2-year College Degree
- ❍ 4-year College Degree
- ❍ Masters Degree
- ❍ Doctoral Degree
- ❍ Professional Degree (JD, MD)

Please indicate your racial/ethnic group.
- ❍ African American
- ❍ Asian
- ❍ Hispanic
- ❍ Native American
- ❍ Pacific Islander
- ❍ White/Caucasian
- ❍ Other (Please specify) ____________________

Please indicate your native language.
- ❍ English
- ❍ Other (Please specify) ____________________

Do you own a touchscreen smart phone (like an iPhone or Android phone)?

- ❍ Yes
- ❍ No

[If Yes to above] What kind of smart phone do you own?

- ❍ Apple iPhone
- ❍ Android phone
- ❍ Windows phone
- ❍ Blackberry phone
- ❍ Other smart phone
- ❍ None of the above
- ❍ I don't know

[If No to Above] Do you have experience using any of the following touchscreen phones? (Select all that apply)

- ❑ Apple iPhone
- ❑ Android phone
- ❑ Windows phone
- ❑ Blackberry phone
- ❑ Other smart phone
- ❑ None of the above
- ❑ I don't know

The next task will require you to read a passage and then answer questions about what you've read. Read completely through a passage; then answer the questions following that passage. You may look back at the material you have read, but do not puzzle too long over any one question. Your score is based on the number of correct responses. Since there is no penalty for incorrect answers, it is to your advantage to mark every question you read. When you are ready to begin, click Next.

Many insects communicate through sound. Male crickets use sound to attract females and to warn other males away from their territories. They rub a scraper on one forewing against a vein on the other forewing to produce chirping sounds. Each cricket species produces several calls that differ from those of other cricket species. In fact, because many species look similar, entomologists often use the calls to identify the species. Mosquitoes depend on sound, too. Males that are ready to mate home in on the buzzing sounds produced by females. The male senses this buzzing by means of tiny hairs on his antennae, which vibrate only to the frequency emitted by a female of the same species. Insects may also communicate by tapping, rubbing, or signaling. Fireflies use flashes of light to find a mate. Each species of firefly has its own pattern of flashes. Males emit flashes in flight, and females flash back in response. This behavior allows male fireflies to locate a mate of the proper species. However, they must beware of female fireflies of the genus Photuris, which can mimic the flashes of other species. If a male of a different species responds to the flash of a Photuris female and attempts to mate, the female devours him. This is surely one of the more unusual behavioral adaptations in the enormously successful world of insects.

When male fireflies emit flashes,

- ❍ female fireflies ignore them.
- ❍ they become fatigued within one hour.
- ❍ other insects fly away immediately.
- ❍ female fireflies flash back at them.
- ❍ they exhaust their food supply.

Male mosquitoes use the buzzing sound produced by females to

- ❍ locate food.
- ❍ locate water.
- ❍ identify a mate.
- ❍ accompany their "songs."
- ❍ drown out their "songs."

Male crickets use sound to

- ❍ call other males.
- ❍ frighten off females.
- ❍ corral their offspring.
- ❍ confused their predators.
- ❍ attract their mates.

Fireflies of the genus Photuris can
- ❍ be easily caught.
- ❍ be imposters.
- ❍ grow unusually large.
- ❍ flash brighter than other fireflies.
- ❍ be found in all climates.

In the phrase "home in on the buzzing sounds," home means
- ❍ travel
- ❍ house
- ❍ listen.
- ❍ focus.
- ❍ join.

For the next section of this survey, you'll want to be in a naturally-lit area that enables you to sit about 2-3 feet away from your screen with minimal glare. Next, you'll see a series of pictures. For each picture, try to identify the hidden number as quickly as you can. If you see a number, type it in the text box below the image. If you don't see any number, simply type the letter "n" in uppercase or lowercase.

Type any number seen. Type n or N if no number seen. ___

Type any number seen. Type n or N if no number seen. ___

Type any number seen. Type n or N if no number seen. ___

Type any number seen. Type n or N if no number seen. ___

Type any number seen. Type n or N if no number seen. ___

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Type any number seen. Type n or N if no number seen. ___

Type any number seen. Type n or N if no number seen. ___

Type any number seen. Type n or N if no number seen. ___

Type any number seen. Type n or N if no number seen. ___

Type any number seen. Type n or N if no number seen. ___

Finally, please provide your @ncsu.edu email address. We will contact you at this email address if you qualify to participate in the study. ____________________

Thank you for taking the time to complete this survey! If you qualify for experiment #2008, you will be contacted soon to schedule your lab visit. If you have any questions in the meantime, please contact abenglis@ncsu.edu for further information.

Appendix C

Post-Warning Questionnaire

Please answer the following questions by reflecting on the trial you just experienced.

Did you experience an **Emergency Alert** during the session you just completed?
- ❍ Yes
- ❍ No

Please indicate your agreement with the following statements based on the Emergency Alert you experienced.

	Strongly Disagree	Disagree	Neither Agree nor Disagree	Agree	Strongly Agree
I am in the warning area.	❍	❍	❍	❍	❍
The weather event is severe.	❍	❍	❍	❍	❍
The weather event will likely cause damage.	❍	❍	❍	❍	❍
The weather event is certain to happen.	❍	❍	❍	❍	❍
I would contact my loved ones at home and tell them about the storm.	❍	❍	❍	❍	❍
I would contact my friends in the area and tell them about the storm.	❍	❍	❍	❍	❍
This message includes specific information that I can use to protect myself, my family, and/or my property.	❍	❍	❍	❍	❍
The warning was urgent.	❍	❍	❍	❍	❍
The warning was helpful.	❍	❍	❍	❍	❍
I need more information before I decide how to respond to this warning.	❍	❍	❍	❍	❍

How would **you behave** if you received this warning?
- ❍ Take shelter
- ❍ Prepare but don't take shelter
- ❍ Do nothing

How do you feel **others would behave** if they received this warning?

- ❍ Take shelter
- ❍ Prepare but don't take shelter
- ❍ Do nothing

Appendix D

Specific Severe Weather Experience Questionnaire

Please indicate **your perception** of the hazard level of each of the following weather events.

	1 - No hazard at all	2	3	4	5 - Extremely hazardous
Tsunami	❍	❍	❍	❍	❍
Tornado	❍	❍	❍	❍	❍
Extreme Wind	❍	❍	❍	❍	❍
Hurricane	❍	❍	❍	❍	❍
Typhoon	❍	❍	❍	❍	❍
Flash Flood	❍	❍	❍	❍	❍
Dust Storm	❍	❍	❍	❍	❍

Have you **ever experienced** any of these weather events?

	Yes	No	I don't know
Tsunami	❍	❍	❍
Tornado	❍	❍	❍
Extreme Wind	❍	❍	❍
Hurricane	❍	❍	❍
Typhoon	❍	❍	❍
Flash Flood	❍	❍	❍
Dust Storm	❍	❍	❍

Please answer the following questions reflecting on your past experience **specifically with tornadoes**.

How many tornadoes have you experienced previously?
- ❍ 0
- ❍ 1-3
- ❍ 4-6
- ❍ More than 6

How many tornado warnings have you received in the past?
- ❍ 0
- ❍ 1-3
- ❍ 4-6
- ❍ More than 6

Please indicate your past experience about **tornado occurrence** given warning.
- ❍ Never

- Rarely
- Sometimes
- Often
- All of the Time

Please indicate your past experience about **tornado severity** given warning.

- Less
- Same
- More